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AFOSR-TR- 71-0786

AD721218

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DEPARTMENT OF PSYCHOLOGY

The University of Michigan, Ann Arbor

Interference in Short-Term Retention of Discrete Movements

REGINALD AUSTIN SORBY ADAMS

Technical Report No. 24

September 1970

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THE UNIVERSITY OF MICHIGAN

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DEPARTMENT OF PSYCHOLOGY

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Reginald Austin Sorby Adams

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This research was supported by the Advanced Research Projects Agency, Department of Defense, and monitored by the Air Force Office of Scientific Research, under Contract No. AF(638)-1736 with the Human Performance Center, Department of Psychology, University of Michigan.

PREFACE

This report is an independent contribution to the program of research of the Human Performance Center, Department of Psychology, on human information processing and retrieval, supported by the Advanced Research Projects Agency, Behavioral Sciences, Command and Control Research, under Order No. 461, Amendments 3 and 5, and monitored by the Behavioral Sciences Division, Air Force Office of Scientific Research, under Contract No. AF 49(638)-1736.

This report was also a dissertation submitted by the author in partial fulfillment of the degree of Doctor of Philosophy (Psychology) in the University of Michigan, 1968. The doctoral dissertation committee was: Professor Arthur W. Melton, Chairman, Associate Professor Wilfred M. Kincaid, Associate Professor Edwin Martin, and Associate Professor Richard W. Pew.

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ABSTRACT

Although there has been a considerable amount of work on short-term memory for verbal material, little has been done to examine the extent to which the findings applicable to this area can be generalized to non-verbal material. Some work with discrete movements has indicated that, unlike verbal material, there is a rapid, apparently spontaneous decay of a discrete movement over a short interval of time, even when long intertrial intervals are used. It is also found that, although the interpolation of information-processing tasks in the retention interval does not affect the retention of discrete movement, retention is adversely affected by the interpolation of additional motor movements.

A series of three experiments examined retroactive interference in the retention of discrete movements, and used this technique to examine the encoding of a discrete movement. The apparatus used for this purpose was a manual lever which could swing in a horizontal plane. The lever could be moved by S, or it could be mechanically driven, moving S's arm through some predetermined angle.

The first experiment involved a retention interval of 9 sec., with three interpolated movements. Effects examined were whether recall over the same path as used during presentation was any better than recall over a different path, whether there were any effects associated with the direction of movement during presentation and recall, and whether there was any significant practice effect in this situation. Results showed a significantly increased absolute error resulting from the interpolated movements, but none of the other manipulations had any effect.

In the second experiment, the position of interpolated movements within the retention interval was examined, as there is an indication in the verbal literature that interpolated material is most detrimental when it occurs early in the retention interval. Results showed a significant tendency for recall to be poorer when material was interpolated towards the end of the retention interval. Possible reasons for this were discussed, and it was concluded that the spontaneous decay effects found with discrete movements were responsible. Similarity effects along the dimension of angle size were not found. There was no tendency for recall to be poorer when the interpolated angle was closer in size to the target angle, nor for the poorly-recalled angles to err towards the magnitude of the interpolated angle.

In the third experiment, the interpolated material involved different components of a complete movement, as it was argued that those components which were most important for the encoding of a movement would produce the greatest interference. Interpolated material included, (a) preparation of the movement, in which S began a movement which the apparatus completed for him,

and (c) passive movement, in which S relaxed while the apparatus moved his arm through the entire angle. Results indicated that forgetting was directly related to the amount of motor output produced by S during the retention interval. A novel and independent means has therefore been used to show that the most important information used to encode a discrete movement is the motor output required to execute that movement.

CHAPTER I

THE RETENTION OF DISCRETE MOVEMENTS

In the past few years there has been a rapid increase in the number of studies concerned with the retention of discrete movements. The responsibility for this lies largely with the demonstrations of Adams and Dijkstra (1966) and Posner and Konick (1966a) that discrete motor movements could be used to study similarities between verbal and motor short-term memory (STM), since they are amenable to many of the manipulations that have long been favorites in the verbal field. While this recent literature has largely been concerned with showing whether decay or interference effects predominate in motor STM, there is a body of earlier work concerned with the general question of how a motor movement is retained under circumstances where vision is not used. Both of these areas will be covered in the present review. One large body of literature which will be omitted is the work on knowledge of results, an area adequately reviewed by I. McD. Bilodeau (1966).

The Encoding of a Discrete Motor Movement

Except for some earlier studies in the German literature (referred to in Hollingworth, 1909), the earliest known study devoted to the performance and retention of discrete motor movements is Woodworth (1899). This covers a wide range of aspects of the performance of voluntary movements, and contains many simple but astute observations, and a wealth of experimental data. Its importance is only slightly reduced by the fact that Woodworth used himself as his _S_.

On the performance of discrete movements, Woodworth raises the question of whether a given movement extent feels any different if made at different

degrees of contraction of the muscles involved. The S stood in one position in front of a blackboard, with his eyes closed, and drew a series of four or five subjectively-equal lines, end to end, beginning as far to the left as possible, and ending as far to the right as possible. It appeared that those lines drawn at the middle of the arm's movement were consistently longer than those at either end. Similar results were obtained by Hollingworth (1909) who had Ss move a slider along a track under similar conditions. The conclusion drawn is that because movements in the middle of the limb's range are more common, they are the easiest, and give rise to less sensation than equal movements at the extremes. Consequently, in order to produce movements which give rise to equal sensations, it is necessary to make movements which are longer in the central area of the range than at the extremes.

Whatever the explanation of the phenomenon, Hollingworth construes these data as evidence that these judgments of extent are not based upon joint sensation. Since equal line segments when drawn at the movement extremes result in less rotation of the shoulder joint than when drawn in the middle, judgment based on this joint would lead to an overestimation of a given length when drawn in the middle, rather than the underestimation which is found. Such an argument as this perpetrates a confusion analagous to the sign/code confusion discussed by Uttal (1967). The simple fact that shoulder rotation expressed in degrees is related in some way to the movements under study does not mean that the movement need be encoded in terms of a linear transformation of the number of degrees of shoulder rotation. It may be that, (a) the shoulder joint has nothing to do with the sensation, or that, (b) the shoulder joint is more sensitive to movements

at its rotation extremes, or even that (c) there is some elaborate transformation of the output of the joint receptors which results in a greater sensitivity at the rotation extremes. Functionally, (b) and (c) are identical. With respect to both of these, Howard and Templeton (1966) quote a finding of Angier (1905) indicating that sensitivity to passive movements is not greatly affected by the position of the joint. The importance of this finding would depend on whether active and passive movements produced the same effect upon joint receptors, a point on which there is little information. In spite of this, Browne, Lee and Ring (1954) found that anaesthesia in a human big toe joint reduced its sensitivity to passive movement. There is some evidence, therefore, that joint sensation is not ruled out as a source of information in making a series of equal-length movements, but there is no evidence that the joint sense itself is directly responsible for the underestimation of movements in the middle of the range.

Hollingworth makes a similar oversight in ruling out muscle receptors as the source of information in making a movement of a particular length. He suggests that because different muscles are used at different points in the whole movement range, the degree of muscle contraction could not provide an adequate basis for such judgments. Yet it is possible that the information from all the muscles involved is integrated centrally to provide a single intensive analog of the position of the limb. Mountcastle, Poggio and Warner (1963) have shown this to occur at the thalamic level in response to movements of the knee joint of the cat and monkey.

One example of the type of study Woodworth carried out has been given above. Many others were also directed towards discovering just what

is sensed and remembered when a movement of a particular extent is made without vision. Possibilities considered are that it is the force exerted, the time taken, the two positions marking the beginning and end of the movement, or some more direct sense of the movement extent, independent of any of the previous factors. In order to test this, Woodworth drew a line under one set of conditions, and then attempted to reproduce the extent under different conditions. To test the effect of force, the S drew a heavy line and then reproduced a light one, or drew a line and then reproduced the extent by marking the end points with dots. For the effect of time, S drew a line with a fast movement and then reproduced it slowly. The S also reproduced a line in a physically different location, as in the equal-segment experiment mentioned above, and even drew a line, swung his arm to one side, and then attempted to reproduce the line in the same position. Measurements were also taken under conditions where more than one of these changes were made. Although significance levels were not given, and some of the measures seem strange in comparison with present customs, the implications are clear. In the line-drawing situation Woodworth used, any change in the conditions between the original line drawing and the reproduction resulted in some decrement in the performance. But even in that condition which was most remote from the original, where a line drawn with the hand was reproduced with the foot, the error was still only in the order of 25% of the original length. The implication, for Woodworth, is that "*there must be a sense of the extent of a movement, a sense which is not reducible to a sense either of its force or of its duration, or of its initial and terminal positions* (*op. cit.*, p. 80, italics in the original)."

One alternative source of information on the movement extent is the innervation, the motor output, required to perform the movement. Woodworth dismisses this as the sole basis on the grounds that other evidence shows Ss to be capable of making a movement and then judging it to be incorrect. If the innervation were the sole basis, how could the S ever know he had moved incorrectly?

Two points will be made with reference to these conclusions. First, when a movement is made, there is nothing else involved but some preliminary decision making, the motor output, and the various kinds of feedback generated by the output. The production of a single movement is undoubtedly a complex affair, but, if there is any phenomenon which can be labelled a direct perception of the movement extent, it must, logically, be a product of these components. Given the integrational capacities of the central nervous system, it is possible that a representation of the extent could be obtained by abstraction from some or all of the components, and it is this abstraction which is retained. The errors that Woodworth found to result from changes in the original conditions would then result from translating the abstraction into the new specific instance. Because the abstraction would probably retain some of the specifics of the original movement, the more of these that are changed, the greater would be the translational difficulty. Before too much is made of this, however, it should be remembered that Woodworth used himself as his S, and the experiments should therefore be replicated.

The second point is in reference to Woodworth's dismissal of the innervation or motor output as the source of information on the movement extent. If what is stored is just the instructions for producing the

original output, or the original motor program, as Keele (1968) would call it, then this program could be activated in order to produce a movement identical with the original. But when some conditions at the time of reproduction are different from the original, a translation of this program would have to be made. Upon execution, the new program could be compared with the old by means of a central feedback loop, and the results of this comparison could lead to a judgment that the movement had not been made correctly. Alternatively, it may be that this translation can only be made at the time of actual execution, hence the fact that judgments of its correctness can only be made after it is too late to correct the translation. Further evidence, largely from studies which have attempted to remove kinaesthetic feedback cues, will be given to support the position that feedback from the movement itself is not an important factor in these judgments.

The Role of Kinaesthetic Feedback

Lashley (1917) reports a study on a patient most of whose leg afferents were missing as the result of a bullet wound to the spinal cord. The fact that the patient could not keep his lower leg in a fixed position, and yet was unaware that he was not doing so, indicated that no functionally useful afferents remained. Lashley indicates that this patient was able to make movements of a consistent amplitude when asked to repeat the same movement several times. In order to do this, he must have been able to remember the original motor outputs, and have been able to reproduce them, since no other information about the absolute positions of his leg or the movement extent was available. We are not told whether intact Ss are able to perform this task with greater accuracy, but Lashley's finding by itself means that

the original motor output can be retained, and contains sufficient information to permit reproduction of the movement. Other tests showed that when the patient was asked to move his leg through a fixed angle against various spring loads he was unable to do so, indicating the fact that afferent stimulation is needed to permit compensation for changes in the load conditions.

Laszlo (1966, 1967) examined the performance of a simple tapping task under kinaesthetic sense loss from ischaemia. A sphygmomanometer was applied to S's upper arm, with the result that after 25 min. or less all kinaesthetic sensation was lost, as judged by the fact that S could not detect a movement of his finger made either by E or by himself. He could, however, still tap his finger, although not at the maximum rate. Since other evidence indicates that Ss possessed sufficient muscular strength to perform the task, the rate decrement is interpreted as evidence that feedback is necessary for the best possible performance of such a task. This suggests that Ss were not performing the tapping task automatically, but were waiting for feedback from each response before initiating the next. Laszlo does present evidence that Ss were able to learn to perform at the non-ischaemic rate after several sessions under ischaemia. It would probably be the case, too, that a musical-instrument player, or someone who had already learned to tap his finger at such a rate that the feedback could not be monitored after each tap, would not be affected by the ischaemia, at least for short bursts of taps. It therefore appears that for rapid motor responding, where feedback is customarily monitored after each response, the response rate is depressed by removal of the feedback, but that Ss can learn to perform without it.

On the question of whether a response can be retained when that response is initially performed without feedback, Knapp, Taub and Berman (1963) and Taub, Bacon and Berman (1965) carried out some informative work on monkeys. They deafferented the forelimb, neck and shoulder of a series of monkeys by sectioning the appropriate dorsal roots. Evidence is given that all sensation was in fact abolished. These monkeys were able to learn to flex their deafferented extremity in order to avoid a shock in a trace conditioning situation, even though they could not see their limb. In order to examine the performance of a more coordinated response, Taub, Ellman and Berman (1966) showed that deafferented monkeys could learn to grasp a fluid-filled bag in order to avoid a shock, again without vision. In order to learn such a response, the motor output required must have been retained from one trial to the next.

In summary, it appears that although feedback is required for the performance of some responses, a response can be retained even though it is performed without feedback. Further quantitative evidence on the retention of a response initially performed without feedback is needed. Until then, the question of whether the presence of feedback at the time of the original performance is of any benefit at all in the retention of the response cannot be answered.

The Similarity of Motor and Verbal Short-Term Memory

Although there have been many studies of factors which affect the forgetting of verbal material, these factors have not been studied to any great extent in the field of motor or skill learning. This has perhaps been for the simple reason that most studies of the long-term retention

of motor responses have shown very little forgetting, and that those manipulations which have been attempted have had little effect on retention.

However, as shown by Ammons, Farr, Block, Neuman, Dey and Marion (1958), some discrete motor tasks are rapidly forgotten, and it may only be continuous motor tasks which are so resistant to forgetting. Adams (1964) has suggested that discrete motor tasks are like verbal responses in their susceptibility to forgetting. There is reason to believe, however, that those tasks which are retained better are not necessarily continuous, but involve "organized patterns of response, or meaningful sequences of motor adjustments (Naylor and Briggs, 1961, p. 6)." In view of Naylor and Briggs' review, this will not be discussed further here. It does seem, however, that certain discrete tasks involve the same order of forgetting over short intervals as is customarily observed in verbal STM studies.

The existence of this rapid forgetting has led a number of workers to study the phenomenon with largely the same techniques that have been brought to bear on the verbal analog. Adams and Dijkstra (1966) had each S move an unseen slide along a metal bar until it struck a stop, and then return the slide to the start, leaving his hand on the slide. After a retention interval of up to 120 sec., during which the stop was removed, S estimated the original movement. Some of the conditions in this experiment involved presenting the movement up to 15 times before beginning the retention interval. The results are shown in Figure 1. For all conditions there was substantial forgetting over at least an 80-sec. unfilled interval, according to a function which appears very similar to the forgetting function for a similar number of presentations of a three-consonant trigram with a filled

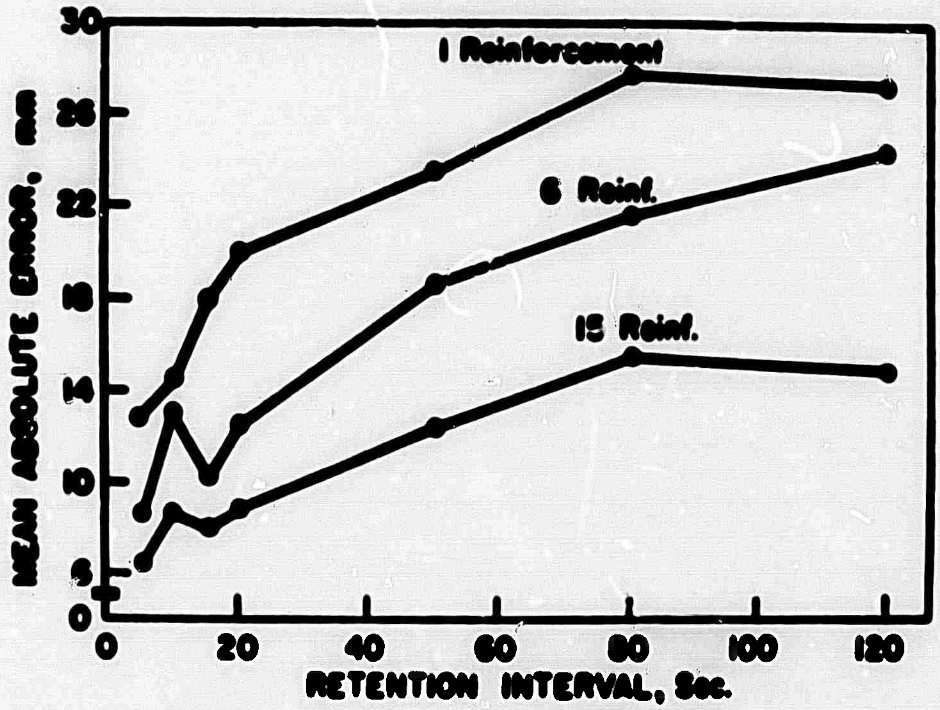

Fig. 1. Performance curves for three reinforcement conditions as a function of retention interval.

retention interval (Hellyer, 1962). The authors consider at some length the possibility that Ss verbally encoded the movement, and that the forgetting represented forgetting of this verbal mediator. If this were so, Ss would have had to label accurately seven positions between 10 and 34 cm, a difficult task to perform reliably given the human absolute-judgment capabilities. And again, if Ss were using verbal labels, much less forgetting than actually occurred would be expected, as there was ample opportunity for rehearsal. Posner and Konick (1966a) were also concerned with the possibility of verbal labelling, and they included a group which was told the actual distance in inches, rather than being presented with the

movement. These Ss generally performed worse than Ss who were actually given the movements without the verbal labels. None of these arguments or controls completely rules out the possibility that verbal labels play some role in the retention of tasks such as these, but they do make that role at most a small one.

Retroactive Effects

The first interference effects to be studied in the short-term retention of motor responses were with material interpolated in the retention interval. In a series of studies Posner (Posner, 1966, 1967; Posner and Konick, 1966a) examined the effect of various information-processing tasks on the retention of a discrete motor movement. The apparatus they used was modelled after Bilodeau, Sulzer and Levy (1962), and involved a lever which moved in a vertical plane in front of S. Two of these levers were used, one for presentation, and one for recall. On each trial S moved one of the levers from one stop to another, then performed the interpolated task, and finally recalled the original movement by attempting to move the second lever through the same angle or distance. Retention intervals of up to 30 sec. were used. Their major finding was that an interpolated paper-and-pencil task has a detrimental effect on recall only when S is able to see the movement of the lever. When the task was purely kinaesthetic, no such effect was observed. This is in contrast to the verbal situation where Posner and Rossman (1965) demonstrated that the greater the amount of information processed during the retention interval, the poorer the recall of the verbal material. Posner (1967) compared retention of a particular position with retention of an angle, or distance. In the latter condition, the starting position for recall was always a different position from that

at which the presentation began. The S was thus forced to retain the angle moved through rather than being given the option of remembering either the angle or a pair of absolute positions. The lack of any significant difference between these two conditions shows that the additional information with respect to position adds nothing to S's performance, a result which would be expected on the basis of Woodworth's (1899) finding that position information is not retained as well as extent information.

Several other studies have investigated the effects of interpolating material of one kind or another in the retention interval during the short-term retention of a discrete movement. Boswell and Bilodeau (1964) had Ss retrieve a pencil from the floor during the retention interval. This movement produced poorer recall than when Ss remained still in front of the apparatus. The measure on which this conclusion was based, however, was the correlation between the response prior to the retention interval and the response after it, taken across all Ss, a measure discussed in more detail by Bilodeau (1966). The initial response was of no fixed length, the S was simply told to make a response which seemed natural to him. Bahrick (1966) has criticized this measure, mainly on the grounds that decreases in this correlation are likely to take place over time as a result of factors other than forgetting. The absolute error data in the Boswell and Bilodeau study did not in fact reflect the differences found with the correlation measure. On the other hand, where differences in correlations are cited as evidence for the differential effect of one condition over another, with the same retention intervals, it is less likely that the effects are artifactual. A further point is that, although the action of retrieving a pencil may have had an effect, it was probably not the result

of one motor task interfering with another, as one verbal task would interfere with another similar verbal task. The action of bending over is too dissimilar to that involved in making the target movement for such an explanation to be plausible. Furthermore, Posner (1967) found no effect of an interpolated paper-and-pencil task, which means that the motor component of such a task was not sufficient to result in a recall decrement. It is much more likely, as Poswell and Bilodeau themselves imply, that the act of bending over to pick up the pencil simply disoriented, or "disengaged," as the authors put it, S from the apparatus, with a consequent drop in performance.

Blick and Bilodeau (1963) performed an experiment in which the interpolated activity was much more closely related to the retained, or target, response. Both the target and the interpolated responses were arcs drawn on paper with the aid of a machine. The target arc was of a fixed length, and 13 trials were given to each S, between each of which S drew an interpolated arc, again of a fixed length. There were five groups of Ss, the size of the interpolated arc differing from group to group. The dependent variables were absolute error and the variance of the algebraic error. Results did not show significance for the Group x Trials interaction, suggesting that the different interpolated arcs did not differentially affect recall. A further experiment compared no interpolation with a single interpolated arc, but again there was no difference between the two groups.

This experiment attempted to maximize the possible effect of the interpolation by providing a series of trials, over which it was presupposed that interference would build up. However, the fact that the interpolated arc was always the same on each trial meant that the interpolated response

was probably being learned to some extent. The conditions therefore involved a single retained response, and a single fairly-well-learned interpolated response, conditions which could not be expected to maximize interference.

An experiment by Williams, Beaver, Spence and Rundell (1969) has shown that interpolated motor movements can result in recall decrements when the target is a similar movement. Using a vertical lever, as in the previous experiments, S made a single movement which was recalled after 0 or 30 sec. There was a series of such trials, with an intertrial interval of 15 sec. During the retention interval S either rested, or carried out a digital paper-and-pencil task, or else he attempted to reproduce on the apparatus some angles drawn on successive pages of a booklet. The paper-and-pencil task varied in the informational load it presented, and some attempt was made to vary the informational load of the angle-reproducing task. Results showed no effect of the digital task, and no effect of varying the informational load in either task. There was, however, a large detrimental effect on recall produced by the motor task, indicating that the similarity of the interpolated task to the retained motor task is an important factor. On this level, at least, there is some relationship to the verbal situation, where the similarity of the interpolated material to the material retained is an important variable (e.g., Wickelgren, 1965).

Pepper and Herman (1970) carried out a series of experiments on the retention of a discrete force response. On each trial S either pulled or pushed on a knob attached to a force transducer, there being no perceptible movement of the knob during this process. During training, S had to pull or push the knob until a line on an associated oscilloscope moved to a predetermined position. On recall, S attempted to apply the same force

without feedback. In the first experiment, the forgetting function was examined over retention intervals from 4 sec. to 60 sec. Analyses of variance on both absolute and algebraic errors indicated no main effects of force magnitude, force direction, or retention interval.

In the lack of any forgetting over these unfilled intervals, this force response therefore behaves very much like verbal material, where there is very little forgetting of a single "chunk" over similar retention intervals (Melton, 1963). The fact that S had visual feedback during the training part of each trial may have been a significant factor, even though there was no visual component during recall. Posner (1967) found that an arm movement which could be seen both during presentation and recall behaved very much like a verbal item in that there was little or no decrement over a 20-sec. retention interval. In Pepper and Herman's second experiment, where an interpolated counting-backwards task was compared with an unfilled retention interval, there was a large detrimental effect of the counting-backwards task. This also agrees with Posner, who found an interpolated information-processing task to be detrimental only when the S could see his arm.

The third experiment reported by Pepper and Herman examined the effect of interpolating a single force response similar to the target response. There was no effect of the relative direction of the interpolated force, i.e., whether it was a push or a pull, but there was an effect of its magnitude. An interpolated force of greater magnitude than the target resulted in increased absolute and algebraic errors, but there was no difference between an unfilled interval and one filled with a force of

lesser magnitude than the target. These data are interpreted as demonstrating classical assimilation effects, as are found, for example, in psychophysical judgments of weights and loudness (Woodworth and Schlosberg, 1954, p. 229). The fact that this force response is on an intensive dimension, as are weight and loudness, where assimilation phenomena appear to be found, may give some insight into the reason why assimilation is found with the force response but not with the arc-drawing response, which is on an extensive dimension. Further work is needed, however, as Pepper and Herman themselves point out that the assimilation phenomenon should work both ways. An interpolated force of lesser magnitude than the target should result in a recalled force of lesser magnitude than after an unfilled interval, just as the reverse should occur for larger interpolated forces. Their results, however, show no effects of interpolated forces of lesser magnitude.

In their final experiment, Pepper and Herman present the target force a number of times before the retention interval. This was in an attempt to replicate the results of Adams and Dijkstra (1966), who showed that in their motor task, repetition results in better recall, just as it does with verbal material. One, three, or seven repetitions were given prior to a 20-sec. retention interval. The results of this experiment were contrary to previous findings in that repetition actually resulted in increased error, for both absolute and algebraic errors. The authors interpret this as a further example of assimilation effects, where repeating the response results in an augmented trace. An alternative possibility is that during the repeated presentations S̲ was not able to achieve exactly the same force each time, with the resulting confusion among the traces leading to

an increased error. One possible test of these two explanations could be achieved by examining practice effects. It should be possible for S to learn to compensate for the assimilation phenomenon, but not for the trace-confusion effects. Further insight could also be gained into this process by presenting a series of reinforcement-test (RT) sequences prior to the retention interval, rather than just reinforcements alone. The trace-augmentation explanation would be supported if the tests indicated a steadily-increasing response tendency.

In conclusion, it appears that Pepper and Herman have obtained effects with a force response which are significantly different from those found with some other motor responses. The possibilities remain that these results have arisen either from the visual guidance used during the training, or from the fact that the force response is on an intensive continuum, while other motor responses examined have been of an extensive nature.

Proactive Effects

In the short-term retention of verbal material, proactive effects are perhaps stronger than retroactive effects, and have been subjected to a wide range of experimentation. Keppel and Underwood (1962) were responsible for a clear demonstration of the effects of prior material. Since then, evidence has been amassed in support of the hypothesis that when similarity effects are responsible for interference in STM, it is only differences along an acoustic dimension which are important (e.g., Wickelgren, 1966; Bruce and Murdock, 1968). On the other hand, there is evidence that interference is also related to differences along a semantic dimension (Wickens and Eckler, 1968; Shulman, 1969), and Hintzman (1967) has suggested that an important dimension is that of place of articulation.

The motor nature of this articulatory-coding dimension gives impetus to the search for further similarities between verbal and motor memory.

A prominent finding in the field of verbal STM is that retention increases as the intertrial interval increases. In the terms of interference theory, proactive interference is a decreasing function of the intertrial interval (e.g., Peterson and Gentile, 1965; Loess and Waugh, 1967). Several authors have construed the results of the Adams and Dijkstra (1966) experiments as evidence that there are no proactive effects in motor learning. However, these authors used only a single, rather long (3 min.) intertrial interval, in a deliberate attempt to minimize any proactive effects, and they did not analyze results as a function of the number of prior trials.

A direct test of the effect of intertrial interval was carried out by Montague and Hillix (1968). A linear motor response was used, as in Adams and Dijkstra (1966). Each trial consisted of four massed RT pairs, followed by a retention interval of 5 or 80 sec., followed by a final test. An intertrial interval of 5, 20 or 80 sec. then followed. The two retention intervals and three intertrial intervals were both between-group variables. Results showed better retention for the three groups with the 5-sec. retention interval than for those with the 80-sec. interval, but no difference resulting from intertrial interval. An examination of performance on the four RT pairs, however, indicated a strong interaction between RT pair and intertrial interval. After a 5-sec. intertrial interval, performance on the first test was significantly worse than after an 80-sec. intertrial interval, but this difference vanished by the fourth RT pair. There were therefore some effects of the temporal proximity of prior responses, but not the large interaction between intertrial interval and retention interval that

was found by Peterson and Gentile (1965) for verbal material. One reason for this may have been that the four RT presentations resulted in such over-learning of the response that it was not susceptible to interference over the retention intervals used. Another reason, suggested by the authors, is that the seven different response lengths used, ranging from 10 cm to 34 cm in 4-cm steps, may have been highly discriminable, and therefore minimally interfering. But if this were so, no proactive effects would be expected, even at the first of the four RT presentations.

Two experiments have recently attempted to demonstrate the effects of prior movements on the retention of a movement. Ascoli and Schmidt (1969) and Stelmach (1969a) both presented either 0, 2 or 4 movements prior to a target movement, and found that retention was worse the greater the number of prior movements. In both cases, however, S was required to recall all the presented movements in the reverse order of presentation, but only the first-recalled movement, the target, was recorded. This was because Bjork, LaBerge and Legrand (1968) have shown that if S is told to forget potentially interfering material, it interferes less. In both the motor studies under discussion the authors were concerned to maximize interfering effects, so Ss were required to recall the interfering material. However, in introducing this requirement, the memory load for each trial was made directly proportional to the number of prior responses. In view of the rapid decay of a movement response, it would seem that such responses are difficult to remember. Large effects of the number of responses retained at a time would therefore be expected, which means that the results of the experiments under discussion were more likely to have

been caused by the memory load factor than the specific prior material. Furthermore, there is no reason why proactive effects would not be expected even if the prior responses were not being retained at the time of the test on the target response. All that is required, if the verbal analog is to be followed, is that a series of RT presentations be made just prior to the target presentation.

Stelmach (1969b) examined proactive similarity effects in the retention of motor movements over intervals of up to 50 sec. Each trial involved five responses, the last of which was the target response. As in the previous experiments, all responses were recalled in reverse order, but performance on the target response only was recorded. The four prior responses were all either $\pm 5°$, $\pm 10°$, or $\pm 15°$ from the target, two larger and two smaller responses being given in random order. Results indicated a significant effect of prior-response similarity on both absolute and algebraic errors. This effect was such that the greater the similarity the less the error, the reverse of the usual finding in the verbal field (e.g., Wickens, Born and Allen, 1963). The fact that there appeared to be no difference between the $\pm 10°$ and the $\pm 15°$ conditions, but a large difference between these two and the $\pm 5°$ condition, led the author to suggest that <u>Ss</u> may have viewed the target response as identical to the $\pm 5°$ responses. The five presentations would therefore have been interpreted as five presentations of the one movement. Since 5° difference in displacement corresponded to a movement difference of only about .25 in., with target movements from 2 in. to 5 in., this interpretation is plausible. It could be tested by including a condition in which there were no prior responses, and if correct, recall for the 5° condition would be better than

for the no-prior-response condition. There is the further possibility, again suggested by the author, that when a series of similar movements are given, S may simply have aimed, on all five recalls, for the mean of the series, a strategy which would result in a low error. Where dissimilar movements were involved, any order confusion would automatically result in large errors. Such order-retention problems would be partly ameliorated by giving a series of RT presentations, rather than requiring S to retain five movements.

In general, it seems that there is no clear evidence for proactive effects in motor STM, although what evidence there is suggests that such effects may exist. The major difference that has emerged between motor and verbal STM is that the motor response appears to decay rapidly over short intervals, even when as much as 3 min. is allowed between trials. A more conclusive test of this effect would result from an examination of first-trial retention, thereby eliminating all possible proactive material. On the other hand, on the basis of verbal data, 3 min. would seem sufficient to eliminate prior effects.

Rehearsal

In the area of verbal STM, rehearsal plays such a great part that if any recall decrement is to be observed over short intervals, active rehearsal must be prevented with some kind of distractor, such as counting backwards. The retention curve shown by Adams and Dikjstra (1966, Figure 1) for a single reinforcement of a motor response mirrors very closely the curve for the retention of a three-consonant trigram over similar intervals, when rehearsal is prevented (Melton, 1963). This suggests that a major difference

between the motor and verbal responses is that there is no obvious way of rehearsing the former. It is interesting to speculate upon the possible way in which S could rehearse a motor movement, if permitted. Of course, one major difference between the verbal and the motor situation is that in the verbal case, so long as S perceives the stimulus accurately, and it is less than the memory span, he can rehearse knowing that he is rehearsing the correct response. The class of responses which is accepted as "correct" is certainly relatively wide, but its membership is never in doubt. In the motor case, however, S can have no such certainty, since the response lies on a continuum not divided in the way articulated sounds are divided into letters and words. Nevertheless, although S may not be able to rehearse the exact response, his performance may be improved if he is allowed to rehearse in some way. And the way in which he rehearses may suggest the way in which the response is encoded. On the other hand, the problems associated with rehearsal in the motor mode have led Atkinson and Shiffrin (1968) to suggest that "rehearsal in modes other than the verbal one [is] either not possible or of no value (p. 99)."

Conclusion

There are obviously many problems involved in the interpretation of the results of motor memory studies, and in relating them to verbal memory. Almost all of these arise from the nature of the motor response and its measurement. With the discrete motor response, absolute error has been the favoured measure, but algebraic error and its variance, and correlational measures, have also been used. Until the relationship of these measures to a wide range of manipulations is examined, the meaning of each of them cannot be evaluated.

An ever-present problem with discrete motor responses is that they inherently lie on a single distance continuum, and at present the only measure of performance has been the distance or angle moved through. Because of this continuum, any recall, including a wild guess, will bear some measureable relationship to the target. The effect of this is to introduce questions about just how similar, in terms of movement extent, a response has to be before it is considered identical. Some psychophysical data on movement extents would be extremely helpful here. The same problem appeared in the verbal field in the guise of the Skaggs-Robinson hypothesis, a problem which was elucidated by the component analyses of Osgood (1949) and Martin (1965). Some similar analysis may well be required in the motor field before further progress can be made with these discrete responses, and before they can be related to the continuous movements of skill and tracking studies. Battig (1966) has suggested an increased use of transfer studies in the examination of the components of a motor task, and Fox (1966) has given some examples of how similarities between motor and verbal tasks may have been obscured by methodological and measurement differences. Further similarities may appear as the notion of articulatory coding (Hintzman, 1967) in verbal learning is developed. Although some direct tests of the similarity between verbal and motor memory have been attempted, there is still the question of whether the differences that have appeared are genuine, or a result of methodological inadequacies.

CHAPTER II

EXPERIMENT I

In the present motor retention situation, the only previous evidence for retroactive interference is from the experiments of Williams et al. (1969), which involved an unspecified number of interpolated movements. However, since their Ss were told to move as rapidly as possible, it is likely that they were able to execute more than just three or four movements in the retention interval of 30 sec. In the present experiment each movement will be paced by the apparatus, and in some conditions a short "preparation time" will be necessary before the actual execution of the interfering movement. Since these requirements make it difficult to present interfering movements at a rate faster than one every 3 sec., it was decided to carry out a preliminary experiment in which the interfering effect of just a few movements would be examined. Previous evidence indicates that there will be considerable forgetting even when there is no interpolated movement. The use of a long retention interval may therefore result in a ceiling being reached which would reduce the observed effect of interpolated movements. The problem of a ceiling effect is aggravated by the fact that even though the response has been forgotten completely, any recalled movement will bear some measurable relationship to the target movement. The maximum possible amount of "forgetting" is therefore automatically reduced by the nature of the task. Because of this, a retention interval of 9 sec. was used, in an attempt to reduce the amount of forgetting that would occur when there was no interpolated material. Three movements were interpolated in this interval.

Several other variables were also examined in this experiment. One factor which has not been carefully controlled is the movement of S's arm during the retention interval. In the Williams et al. (1969) study, and in fact in all the relevant studies, Ss have had either to move the lever back to the starting point themselves, or else to remove their hand from the lever while E moved it back to the start. In all these cases the reproduced movement was over a path physically identical to that used for presenting the movement. In the case of Posner and Konick (1966a), where in one condition the reproduced movement was on a different piece of apparatus, S had to move his arm from the first lever to the second during the retention interval. Although this study found no effect of changing the location of the reproduction from a position physically identical to that of the presentation to one physically displaced, all the conditions required S to remove his arm from the lever between presentation and recall.

In the present experiments it was decided to try to have no additional movements made by S during the retention interval. In other words, after making the initial movement, S was to leave his hand on the lever, without moving it, until either an interpolated movement or reproduction was required. This meant that in the rest condition S could only make the reproduction by moving an equivalent distance further on in the same direction as the initial movement, or else by moving the lever back to the starting point. If S remembers absolute positions as well as, or instead of, movement extents, moving the lever back to the starting point would result in better recall. This was examined in the first experiment.

In the rest condition, these two possible methods of reproduction are confounded with direction of movement. The first must always be

carried out in the same direction as the initial movement, and the second in the opposite. In the condition where there is interpolated activity, however, it is possible to remove this confounding. This was attempted by having two conditions for reproduction in the same direction in the interference conditions. In one, the reproduction was over a path different from that of the initial movement, and in the other, it was arranged that, within limits, S would be back at the original starting point just prior to reproduction, so that the reproduction would be over the same path and in the same direction as the initial movement. Finally, this experiment examined the effect of direction of presentation, and also attempted to see if there is any major practice effect in this situation.

Method

Apparatus

The apparatus used was the same in all experiments, and is illustrated in Figure 2. Fitted to a right-handed student's desk-chair was a lever which could rotate in a horizontal plane through an angle of 130°. In its left-most position, the lever was parallel to S's frontal plane, i.e., parallel to the back of the chair. For the purpose of measuring angles, this position was regarded as 0°, and angles were measured to the right of this point. The lever itself was equipped with an elbow support and an adjustable vertical bar which S gripped with his hand. The distance from the lever's pivot to the vertical bar was adjustable from 28 to 35 cm, and for each S the position was set so that the pivot was approximately 2.5 cm distal from the tip of the elbow.

The lever was fitted with a bidirectional motor, a clutch, and a brake. With the clutch engaged and the motor on, the arm rotated at

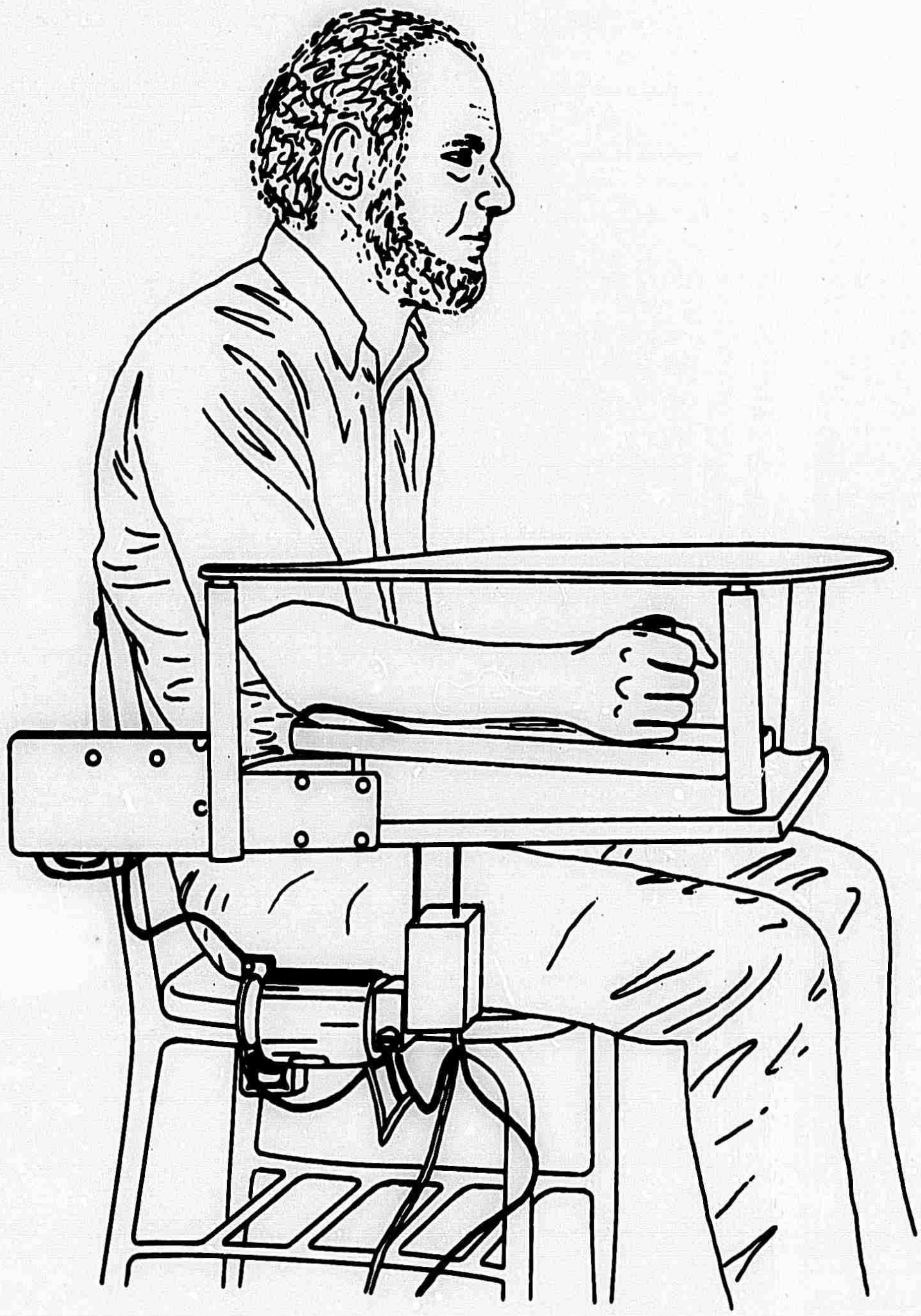

Fig. 2. An illustration of the apparatus, showing an S grasping the lever. The screen is approximately 120 cm (48 in.) in front of S's eyes.

54 rpm, and under these conditions a torque of 15 kg-cm (212 oz.-in.) was sufficient to cause the clutch to slip and the arm to stop moving. With the clutch disengaged, the torque required to overcome the sliding friction was approximately 6.55 kg-cm (49 oz.-in.) and did not vary appreciably over the range of the lever's movement. With the brake applied, the "slop" in the lever's position was less than $\pm 1°$. There was a shield over the lever so that S was not able to see either the lever or his arm.

Instructions were presented to S on a CRT display controlled by a PDP-1 computer. The S's eyes were approximately 120 cm (48 in.) from the screen, and the letters displayed were 11 cm (7/16 in.) high. During the experiment, S and the display were isolated from E and the computer. Because of the noise made by the solenoid-operated brake, S wore close-fitting headphones with white noise, the level of which was high enough to mask the sound of the brake, but not so loud that any S, when asked, reported it to be uncomfortable.

The computer was used, via a relay buffer, to switch on the motor power and direction, the clutch, and the brake, and via a potentiometer and an analog-to-digital converter, to monitor the position of the lever. All experimental events were therefore under computer control.

Design

A 6 x 8 x 2 factorial design was used, with six experimental conditions, eight target angles, and two directions of presentation, making 96 trials per replication. There were 28 Ss, each of whom was given some practice, and then a single block of 96 trials in a session lasting approximately 1 hr. 20 min. The six conditions, which included two rest and four interference conditions, were as follows.

1. Rest; presentation and recall in the same direction.
2. Rest; presentation and recall in opposite directions.
3. Interference; presentation and recall in the same direction from the same starting point.
4. Interference; presentation and recall in the same direction from different starting points.

5, 6. Interference; presentation and recall in opposite directions. Those trials from the first half of the experiment were designated as belonging to Condition 5, and those from the second half to Condition 6.

These six conditions were chosen so that a set of five orthogonal planned comparisons, each with a meaningful interpretation, could be carried out. Details of the comparisons and their interpretations are left for the results section.

Eight different angles were defined as target angles. They were 5°, 10°, 15°, 20°, 25°, 30°, 35°, and 40°, and in each condition each angle occurred once with each presentation direction.

Except for the duplication represented in Conditions 5 and 6, each trial was unique, making counterbalancing within each S impossible. However, some attempt was made to ensure comparability between the first and second halves of the list presented to each S. For the two rest conditions, the angles of 5°, 15°, 25°, and 35° were used in the first half of the experiment, and the others in the second half. For the trials in Condition 3, presentation was to the left in the first half for the odd angles and to the right for the even angles, with the reverse for the second half. Condition 4 was treated as Condition 3, but with left and right interchanged.

Those interference trials with presentation and recall in opposite directions which occurred in the first half were defined as belonging to Condition 5, those from the second half to Condition 6. Except for these restrictions, the trials occurred in random order.

Using a set of rules to be described below, a list was constructed which was presented to four Ss. The list was divided into six equal "blocks," which were presented to the four Ss in these orders.

1	2	3	4	5	6
6	5	4	3	2	1
3	2	1	6	5	4
4	5	6	1	2	3

For the first experiment, four lists were prepared, but only the first two orderings of the last list were used. It was initially intended that at least 16 Ss would be run in this experiment, but when the computer broke down after 14 Ss, the data was examined. Since the results were clearly significant for the main manipulation, the experiment was terminated at that point, even though the balancing was incomplete.

The construction of each trial.--For each trial the starting point for each target movement was chosen from within a 90° "working range," using only whole numbers for the sake of simplicity. The working range was between 20° and 110°, so that there was an additional 20° of movement at either end, before the lever struck against the permanent stops. The starting points for all movements were chosen randomly, but with the restriction that if each movement was made accurately the lever would never move outside the working range. This restriction meant, for example,

that if the target angle was 40° to the right in Condition 1, where presentation and recall were in the same direction, the starting point was in fact chosen randomly from the range between 20° and 30°.

In Conditions 3 to 6, the interference conditions, three movements were interpolated between presentation and recall, each movement taking approximately 3 sec. The finishing point for each of these movements was chosen randomly from the working range, with the restriction that the distance from the end of the previous movement must be greater than 5°. This restriction was imposed for two reasons. Firstly, to minimize the possibility that S might be asked to make a very small movement which would not be recorded, and secondly, because the interfering effect of a very small movement might not be comparable to that of larger movements. There were further restrictions on the finishing position for the last of the interpolated movements, their position being, of course, the starting position for recall. In Condition 3, the finishing position for the third interpolated movement was completely fixed, as it had to be the same as the starting point for the target movement. In this case, the finishing position for the second interpolated movement had to be more than 5° from this point. In Condition 4, where presentation and recall were in the same direction but from different starting points, the finishing position for the third interpolated movement was at least 5° distant from the starting point of the target movement. Finally, for all conditions, the starting point for recall was such that S could not predict the direction of recall. For example, if the retained movement was 20°, the starting position for recall was chosen from between 40° and 90°.

Procedure

The program controlling the experiment was written to present a movement for retention, any number of interpolated "events," and then to ask for recall, approximately 3 sec. being allowed for each of these.

Each trial, including the first, began with the display of the word "REST" for 8 sec. During this period the lever was set to the starting position for that trial. At the end of this period, the words "GRASP LEVER" were displayed for 4 sec. and S was instructed to rest his arm on the lever at this point. The words "MOVE AND REMEMBER" then appeared, with an arrow beneath them indicating to S the appropriate direction for him to move. On this signal S moved the lever in the direction of the arrow, until the brake came on. The brake, which stopped the lever much as if it had hit against a fixed stop, remained on for 2 sec., after which the retention interval followed.

For the rest conditions, the screen remained blank during the retention interval, and S was instructed to keep his arm still until some instruction appeared. For the interference conditions, a number and an arrow appeared on the screen as soon as the brake was released. The number represented the distance in degrees through which S was to try and move the lever, while the arrow indicated the direction. Both the distance and direction were calculated by subtracting the position at which the lever came to rest from the required finishing position for the first interpolated movement, a positive result indicating movement to the right and a negative one to the left. After the number and angle display had been on for 1 sec., the word "MOVE" appeared above it. The S was instructed not to move until this

appeared. Once S started moving, the lever's position was read every 200 msec. The end of the movement was defined as having occurred if the lever's position did not change by more than 2° in any 200-msec. period. The S was allowed 2 sec. to complete the movement, making 3 sec. in all for each interpolated movement. Instructions stressed that each movement had to be made smoothly and deliberately, and that corrections could not be made once S stopped moving.

After the first interpolated movement, the next two followed in the same way. At the end of the third, the word "RECALL" was displayed, together with an arrow indicating the direction. This was a sign for S to try to move the lever through the same angle as he moved it when the "MOVE AND REMEMBER" instruction appeared. The end of this movement was defined in the same way as the end of an interpolated movement, and 3 sec. were allowed for S to finish the movement. At the end of this period, the word "REST" appeared, which was a signal for S to take his arm off the lever and rest it in his lap.

Any time S made a mistake during a trial, a signal appeared for 2 sec. to indicate the nature of the mistake, and then this was followed by "REST," and the next trial was begun. This trial was then repeated at the end of the arbitrary "block" in which it occurred. If S moved in the wrong direction at the beginning of any movement, "WRONG DIRECTION" appeared. "TOO SLOW" indicated that a movement was not completed in the allotted time, while "KEEP STILL" appeared if S moved more than $\pm 1°$ during the retention interval for the unfilled conditions. If S moved before the word "MOVE" appeared during an interpolated movement, "DON'T ANTICIPATE" was displayed. Finally, although the working range was the 90° segment between 20° and

110°, S could move the lever anywhere between 5° and 125°. If he moved it outside this larger range, the words "TOO FAR" were displayed, and that trial was repeated. This in fact occurred very seldom during the experiment, but it was included to avoid the possibility that _ might hit the lever against the permanent stops at 0° and 130°. In such a case, these positions would have been read as defining the end of a movement which S may have intended to go beyond the stops.

When S arrived for the experiment he was seated in the chair, and the handle on the lever was adjusted so that the tip of his elbow was in a constant position. He was asked to move the lever through the limits of its travel, and was shown how to rest his arm in his lap between trials, and how to find the lever by feel, without looking for it visually. The instructions, reproduced in Appendix A, were then read to him. They stressed that the primary task was to reproduce the target movement as accurately as possible, but they also mentioned the measures that were taken on the intervening movements.

Each S was given two practice periods before the main experiment. During the first practice period, which continued until S completed five consecutive trials without error, E remained in the experimental room with S and answered any questions as they arose. Instructions were then given on the bonus system, which was 3 cents each time S reproduced the angle to within ±2° of its correct value. The S was told that he would be given feedback on his performance during the second practice period. This time E remained outside the experimental room, and each time S made a successful recall, E read the error as it was printed out on the computer's typewriter, and relayed it to the S over an intercom. The second practice period ended

when S had attained the $\pm 2°$ criterion three times, or had completed 10 trials, whichever took longer. He was then brought out of the experimental room for a few minutes' rest before beginning the main part of the experiment. The S was told that the experiment would last about 45 min., and that there would be a short rest half-way through. He was then seated, told to put on the headphones, and the experiment began.

Subjects

The Ss were 14 right-handed males who had volunteered to serve in paid experiments. They were paid at the rate of \$1.50 hour, plus a bonus based on performance. All were naive to experiments of this type.

Results and Discussion

The dependent variables were the absolute and algebraic errors, to the nearest degree. The experiment involved a total of 1344 trials, of which 48, or 3.57%, were missing. Although trials on which S made an error were repeated, there were some occasions when the papertape was misread, with the result that an attempt was made to set the lever at some non-existent angle, either below 0°, or above 130°. In such a case the program automatically went on with the next trial. For the purpose of an analysis of variance, the missing data points were estimated using a procedure similar to that suggested by Winer (1962, p. 282). For each S, the data were divided into four sections, by separating the four smaller angles from the four larger ones. Each of these sections was then divided into two further sections by separating the trials with interpolated movements from the others. Data points missing from a given section were estimated using the marginal means from that section. The degrees of freedom for the residual term in the analysis of variance were reduced accordingly.

Overall Analysis

A four-way analysis of variance (Subjects x Treatment Conditions x Direction of Presentation x Angles) was carried out on the absolute errors. An *F* test was not carried out on Treatment Conditions, since these means were to be subjected to a set of planned comparisons. All the other main effects were significant. For the Direction effect, $F(1,13) = 14.14$, $p < .01$, and for the Angles effect, $F(7,91) = 10.14$, $p < .001$. The mean for presentation to the left was 6.74°, and to the right, 5.59°. The means for the Treatment Conditions are given in Table 1, and for the Angles in Table 2.

TABLE I

MEAN ABSOLUTE AND ALGEBRAIC ERRORS (IN DEG.) AND VARIANCES OF THE ALGEBRAIC ERRORS, FOR THE SIZE TREATMENT CONDITIONS: EXPERIMENT I.

	Absolute Error	Algebraic Error	Variance	d.f.
1. Rest; presentation and recall in the same direction.	5.68	-3.18	45.47	221
2. Rest; presentation and recall in opposite directions.	5.03	-0.95	40.23	216
3. Interference; presentation and recall in the same direction from the same starting point.	6.54	-0.48	73.21	211
4. Interference, presentation and recall in the same direction from different starting points.	6.43	-0.46	69.38	214
5. Interference; presentation and recall in opposite directions (1st half).	6.78	-0.13	84.33	213
6. Interference; presentation and recall in opposite directions (2nd half).	6.54	1.03	79.52	215

TABLE 2

MEAN ABSOLUTE AND ALGEBRAIC ERRORS (IN DEG.)

FOR THE ANGLE EFFECT: EXPERIMENT I.

	Angle							
	5°	10°	15°	20°	25°	30°	35°	40°
Absolute Error	3.93	5.10	5.12	5.25	6.08	7.65	7.98	8.23
Algebraic Error	2.17	2.66	1.45	0.83	-2.05	-3.27	-3.51	-3.10

The Angle effect indicates that larger errors are associated with larger angles, while the Direction effect indicates that movements to the right, or away from the body, were reproduced more accurately than those made in the opposite direction, a finding which agrees with data from Brown, Knauft, and Rosenbaum (1948). In an experiment using linear movements, these authors found greater accuracy of reproduction when the movement was away from the body than when towards it. This finding applies to two of three planes of movement they examined. The third plane involved vertical movements, gravity presumably being the cause of the inconsistent results in this case.

In the overall analysis of absolute errors, there were four significant interactions. These were Subjects x Treatment Conditions, $\underline{F}(65,407) = 1.58$, $\underline{p} < .01$, Treatment Conditions x Angles, $\underline{F}(35,407) = 1.60$, $\underline{p} < .05$, Subjects x Angles, $\underline{F}(91,407) = 1.92$, $\underline{p} < .01$, and Directions x Angles, $\underline{F}(7,91) = 2.22$, $\underline{p} < .05$. The significant interactions involving Subjects reflect greater variability across both Treatments and Angles for some <u>S</u>s than for others.

the other two interactions, both involving Angles, are the result of a divergence between the curves at the largest two angles.

The algebraic errors were also subjected to an overall analysis of variance, with results similar to those from the absolute error analysis. The Direction effect was significant, $F(1,13) = 13.52$, $p < .01$, as was the Angle effect, $F(7,91) = 19.63$, $p < .001$. The mean for presentation to the left was -1.89°, and to the right, .50°. Other means are given in Tables 1 and 2.

A sign test was carried out for each S on the sign of the algebraic errors for each trial. Of the 14 Ss, four had significantly more overshoots, three of these being at $p < .01$, with the fourth being at $p < .05$. There were five Ss with no significant difference between the number of overshoots and undershoots, while the remaining five Ss all made significantly more undershoots, all of these being at $p < .01$.

Hollingworth (1909) suggested that when a distance is delimited by having S hit against a fixed stop, there will always be a tendency for S to overestimate that distance on a subsequent reproduction. The present results indicate that this tendency is very much dependent on the S concerned. There is also the slightly negative grand algebraic mean, which suggests that there is, if anything, a prevailing undershooting tendency in this experiment.

The Direction effect for algebraic error is such that movements to the right, which are reproduced on the whole more accurately, are reproduced with a slight overshooting, while those to the left result in a larger undershooting.

The existence of this Direction-of-Presentation effect leads to the question of whether there is also any Direction-of-Recall effect. Such an effect would not make any contribution to the Direction-of-Presentation effect, since each recall direction occurred equally often with each presentation direction. This information, as well as information about the interaction of presentation and recall directions, is available from the means for the Treatment Conditions x Direction-of-Presentation interaction. Planned comparisons were carried out on these means to test for such effects. For absolute error, $F(1,65) < 1$ for both recall direction and its interaction with presentation direction. For algebraic error, the Recall Direction effect was not significant, $F(1,65) = 1.22$, but its interaction with presentation direction was highly significant, $F(1,65) = 9.76$, $p < .01$. The means for this interaction are given in Table 3. It is evident that, within each presentation direction, the constant

TABLE 3

MEAN ALGEBRAIC ERRORS (IN DEG.) FOR THE PRESENTATION DIRECTION X RECALL DIRECTION INTERACTION: EXPERIMENT I.

Recall Direction	Presentation Direction: Left	Right	Mean
Left	-2.33	1.42	-0.45
Right	-1.45	-0.42	-0.94
Mean	-1.89	.50	-0.69

error is least when recall is to the right. This is in keeping with the general finding that movements to the right in this situation are more accurate.

The study of Brown, Knauft and Rosenbaum (1948), which was mentioned earlier, also found that where a range of movements is presented, the smaller ones will be overshot on reproduction, while the larger ones will be undershot, a finding which applied no matter what the range of the movements. This generalization is supported by the present results, which show overshooting for the four smallest angles and undershooting for the four largest ones. This could be a result of guessing. Even if S has completely forgotten the target movement, he is required to make some sort of recall. This "guess" is likely to be near the mean of the movements encountered, since such a movement will minimize the error score on these trials. Even a small number of such responses would result in an overall undershooting tendency for those angles larger than the mean, and an overshooting tendency for those smaller. It should be noted that, although there is an overall tendency towards undershooting, this is not reflected in the results for each angle taken separately, and is in fact small compared with the overshooting and undershooting which appears in the means for the Angle effect. These results have some bearing on the idea that forgetting appears as a "shrinking trace," and they will be mentioned further in this context.

Treatment Effects

The six treatment conditions were subjected to a set of five orthogonal planned comparisons, each accounting for one of the five degrees of freedom associated with this factor. Table 4 gives the weights and mean squares

TABLE 4

WEIGHTS AND MEAN SQUARES FOR THE

FIVE COMPARISONS: EXPERIMENT I.

Treatment Condition	Comparison 1	2	3	4	5
1. Rest; presentation and recall in the same direction.	-2		1		
2. Rest; presentation and recall in opposite directions.	-2		-1		
3. Interference; presentation and recall in the same direction from the same starting point.	1	-1		1	
4. Interference; presentation and recall in the same direction from different starting points.	1	-1		-1	
5. Interference; presentation and recall in opposite directions (1st half).	1	1			1
6. Interference; presentation and recall in opposite directions (2nd half)	1	1			-1
<u>Mean Square</u>					
Absolute Error	442.8	6.6	46.9	1.5	6.7
Algebraic Error	1258.2	188.5	560.3	.1	150.9

associated with each comparison. The error term is the Subject x Treatments interaction mean square, with *df* = 65. This was 34.97 for absolute error and 62.01 for algebraic error. For the absolute error, the only significant comparison was the first, between the rest conditions on the one hand, and the interference conditions on the other, $F(1,65) = 12.66$, $p < .001$. For algebraic error, this comparison was significant, $F(1,65) = 20.29$, $p < .001$,

as was the second comparison, between the two rest conditions, $F(1,65) = 9.04$, $p < .01$.

The absolute error results suggest that there are no differences associated with whether recall is in the same or the opposite direction as presentation (Comparisons 2 and 3 in Table 4), nor with whether same-direction recall is over the same path as presentation or over a different path (Comparison 4). There was also no practice effect within the experimental session, as suggested by the lack of significance associated with Comparison 5 in Table 4.

A brief explanation of Comparison 4 is needed. Since the interpolated movements were entirely under the control of S, it was not possible to ensure that the starting point for recall in Condition 3 was always exactly the same as the starting point for the presentation, nor, for that matter, that these points were, in Condition 4, always the intended 5° or more apart. Because of this, the data were examined to discover the extent to which these conditions were fulfilled. The mean difference between the starting points for presentation and recall was 8.6° in Condition 3 and 22.6° in Condition 4, with associated SDs of 7.0° and 14.4°. Although the difference between these means is highly significant, the relatively large difference associated with Condition 3 has the effect of weakening the conclusion drawn from Comparison 4. On the other hand, in view of the already-existing evidence of Woodworth (1899), the present data supports the conclusion that the absolute position at which the movement occurs is unimportant, and that Ss do in fact remember a movement extent as an extent, rather than as two positions of the limb relative to the body. One of Woodworth's findings was that, as in the

present experiment, shorter movements are reproduced more accurately than longer ones. There should be no differences associated with the length of the movement if S is remembering two positions.

The results of the planned comparisons on the algebraic error were similar to those on the absolute error, with the exception that the comparison between the two rest conditions was significant, indicating a much larger undershooting for the case where recall was in the same direction as presentation. This result is almost certainly an artifact. On a rest trial, when recall is in the same direction as presentation, the lever must be moved through two arcs which sum to an angle twice the size of the presented angle. This will on occasion result in a final stopping point which is close to, or at, a limit of the "working range." The knowledge that, if they go too far beyond this limit, the error signal "TOO FAR" will be displayed, may cause some Ss on some trials to stop short, resulting in an overall undershooting.

Since Bilodeau (1966) has suggested that the variance of errors will increase as a result of forgetting, the variances associated with each of the treatment conditions are given in Table 1, together with the appropriate degrees of freedom. The degrees of freedom are less than the maximum of 223 because of the missing data already mentioned. It is not appropriate to carry out a series of pairwise F tests on these results, since the probability of a type-I error would be raised. However, Cochran's test (Winer, 1966, p. 94) was carried out, giving $C = .215$, permitting rejection at $p < .05$ of the null hypothesis that variances are equal across the set of six. An examination of the variances makes it clear that almost

all of this inhomogeneity is caused by the differences between the rest and the interference conditions. It therefore appears that just three movements, interpolated in a 9-sec. retention interval, are sufficient in this situation to cause a significant increase in forgetting, as measured by the absolute error or the variance in the recall.

CHAPTER III

EXPERIMENT II

There is evidence in the verbal learning literature that there are significant differences in retention resulting from differences in the position of interpolated material within the retention interval. Corman and Wickens (1968) presented consonant trigrams for retention, with another pair of consonants interpolated in the 10-sec. retention interval. Results indicated a non-significant tendency for there to be more forgetting when the interfering material came early in the retention interval than when it came late. Further evidence comes from Ligon (1968), who has shown that in the retention of alphanumeric material over intervals of up to 4 sec., retention is adversely affected when similar items are adjacent to the recalled item. Although evidence has already been given which suggests that interpolated digital tasks do not affect the retention of motor movements, Reid (1967) found that if rehearsal of consonant material is prevented with an interpolated digital task, recall is much worse if rehearsal is prevented early in the retention interval rather than late.

The evidence in connection with verbal material therefore suggests that when either similar material, or material designed to prevent rehearsal, is interpolated in the retention interval, recall is worse if the material is interpolated early.

In the present series of experiments, one was planned in which different types of material were to be interpolated at different points in the retention interval. Given the differences that have already appeared between verbal and motor tasks, it was important to determine

whether the point of interpolation is a significant variable in the present situation. The second experiment examined this question by presenting two different amounts of material at three different points in the retention interval. The overall effect of amount of material was further examined by including conditions with completely filled and with completely unfilled retention intervals.

Method

Design

The apparatus was the same as in the first experiment. In order to reduce the number of trials per replication, the number of angles presented was reduced to six, ranging from 15° to 40° in 5° steps. The retention interval was increased to 12 sec., thereby permitting up to four interpolated movements.

In Experiment I the effects of angles and of direction of presentation were significant, but, although the main effect of angles was of some theoretical interest, none of the interactions of these two factors were of interest. In Experiment II, the interactions of angles with directions of presentation and recall were therefore confounded with the Subjects effect. Within each S, each angle was paired, in a balanced incomplete-block design, with only one of the four possible combinations of the two directions of presentation and the two directions of recall. Across every four lists, however, all possible combinations occurred equally often.

The retention interval in this experiment was 12 sec., permitting four interpolated movements, one in each of the four 3-sec. intervals into which the retention interval was conceptually divided. There were

eight different treatment conditions, in each of which the retention interval was filled differently. In Condition 1, the retention interval was unfilled. In Conditions 2, 3 and 4, it was filled with just one interpolated movement. In Condition 2, this movement occurred in the first position, i.e., in the first of the four 3-sec. intervals. In Condition 3, it occurred equally often in the two middle positions, and in Condition 4 it occurred in the last position. There were then three conditions in which the retention interval was filled with two interpolated movements. These were Conditions 5, 6 and 7, in which the two movements occurred in the first two, the middle two, or the last two positions. Finally, in Condition 8, the retention interval was completely filled with four interpolated movements. The various ways in which the retention interval was filled are shown schematically in Table 5.

Each S was presented with 96 trials, comprising 6 angles x 8 treatment conditions x 2 replications. The trials were presented in random order, with the exception that one replication was completed before the second was begun. Any difference between the replications, therefore, constituted a practice effect. Within a replication, there were as many Condition-3 trials in which the interpolated movement occurred in the second position as in the third, and if a Condition-3 trial had its interpolated movement in the second position in the first replication, it was moved to the third position in the second, and vice versa. Each list was presented to four Ss using the same orderings as in Experiment I.

In making up each list, the rules by which the finishing points for each movement were chosen were the same as in Experiment I, with the exception that, in those trials where there were interpolated movements,

TABLE 5

LOCATION OF THE INTERPOLATED MOVEMENTS WITHIN THE RETENTION INTERVAL FOR EACH OF THE TREATMENT CONDITIONS, WITH THE ASSOCIATED ALGEBRAIC-ERROR VARIANCE FOR EACH CONDITION: EXPERIMENT II.

Condition	3-sec. interval				Variance	d.f.
	1st	2nd	3rd	4th		
1	.	.	.	.	58.98	321
2	X	.	.	.	61.64	328
3	.	X------	X	.	61.12	320
4	.	.	.	X	75.60	330
5	X	X	.	.	57.16	329
6	.	X	X	.	65.01	326
7	.	.	X	X	84.68	327
8	X	X	X	X	80.04	324

no attempt was made to manipulate the starting position for recall relative to the starting position for presentation.

There were again two practice periods, which were continued to the same criteria that applied in Experiment I.

Procedure

The practice sessions and the experimental session were administered in the same way, and with the same instructions, as in Experiment I. Within each trial, whenever the retention interval or any part of it was unfilled, the screen remained blank, and S had to keep the lever still. If he moved, "KEEP STILL" appeared, as before. Again, aborted trials were repeated at the end of a block.

Subjects

There were 28 right-handed male <u>S</u>s, drawn from the same source as in Experiment I, and all naive to experiments of this type. The base pay and bonus were the same as in Experiment I.

Results and Discussion

The experiment involved a total of 2688 trials, of which 75, or 2.8%, were missing as a result of apparatus failures of the same nature as mentioned in Experiment I. Since there was no case where a trial was missing from both the first and the second replication, each missing trial was simply replaced with the corresponding value from the other replication, and the degrees of freedom were reduced where appropriate.

Overall Analysis

A four-way analysis of variance was again carried out on the absolute and algebraic errors, the factors being Subjects, Practice, Treatment Conditions and Angles. The Treatment Conditions will be discussed below. The Practice effect was not significant in either analysis, $F(1,27) < 1$ in each case, but the other main effect for both analyses was significant at $p < .001$. For the absolute error, $F(5,135) = 7.30$ for the Angle effect, while the corresponding value was 25.10 for the algebraic error.

The Angle effect was of the same nature as in Experiment I. In order to illustrate the magnitude of the over and undershooting associated with the small and large angles, respectively, Table 6 shows the algebraic means for the six angles, together with the absolute means.

TABLE 6

MEAN ABSOLUTE AND ALGEBRAIC ERRORS (IN DEG.)

FOR THE ANGLE EFFECT: EXPERIMENT II.

	Angle					
	15°	20°	25°	30°	35°	40°
Absolute Error	5.15	6.08	5.64	6.04	7.43	7.98
Algebraic Error	2.35	2.43	.39	-0.81	-2.47	-3.78

The number of overshoots and undershoots made by each S were examined with the sign test. Eleven Ss undershot significantly more often and 10 overshot significantly more often. The confounding of the interaction of angles and of directions of presentation and recall with the Subjects effect makes the interpretation of these figures difficult. However, the significance of the overshooting and undershooting effects was in all but two cases at the 1% level or better. Combined with the evidence from Experiment I, this leaves little doubt that there are important individual differences with respect to over and undershooting tendencies.

For absolute error, there were significant interactions of Subjects with Treatments, $F(189,870) = 1.39$, and Subjects with Angles, $F(135,870) = 3.67$, both at $p < .01$. As in Experiment I, these reflect greater variability across Treatments and Angles for some Ss than for others. For the algebraic error, there were four significant interactions, all at $p < .01$ or better. The interactions of Subjects with Treatments, $F(189,870) = 1.39$, and Subjects with Angles, $F(135,870) = 3.67$, reflect greater variability for some Ss than others, as was the case for the absolute error. There was also

a significant interaction of Subjects with Practice, $F(27,870) = 2.09$, resulting from a rise in algebraic error for some Ss and a fall for others. There appeared to be no relationship between an S's overshooting or undershooting tendency and whether his algebraic error rose or fell with practice. Of the 11 undershooting Ss, 7 showed a tendency for their algebraic error to fall with practice, while 5 of the 10 overshooters showed such a tendency. Finally, there was a significant Treatment x Angles interaction, $F(35,870) = 1.82$, again a result of a divergence between the Treatment curves at the largest two angles.

In general, the large differences between Ss, and the multiplicity of interactions, casts doubt on the reliability of algebraic error as a measure of forgetting in this situation. It is included in these and subsequent analyses because much has been made of algebraic effects in the literature.

Treatment Effects

The overall effect of amount of interpolated activity on the absolute error is shown in Figure 3. This is averaged across Conditions 2, 3 and 4 to give the mean effect for one interpolated movement, and across Conditions 5, 6 and 7 for two movements. The significance of the effect of number of interpolated movements was tested with a planned comparison in which weights of -3, -1, -1, -1, 1, 1, 1, and 3 were used for the eight treatment means in order. The result was significant at the 5% level, $F(1,189) = 6.54$. This confirms previous results, and goes further in showing a relatively linear increase in absolute error with an increase in the number of interpolated items.

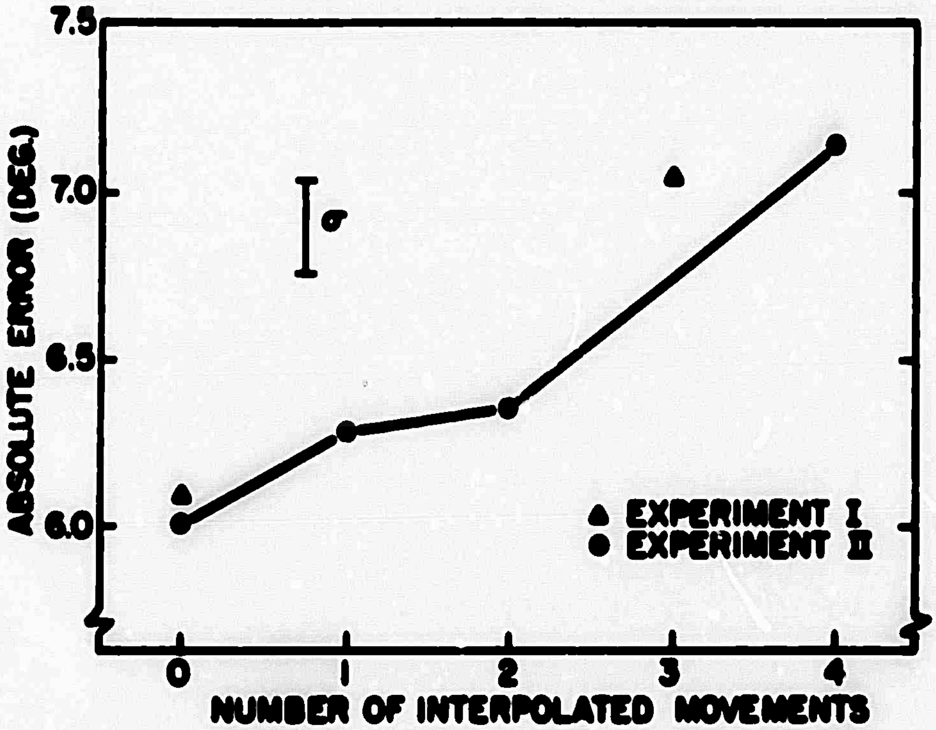

Fig. 3. Absolute error as a function of amount of interpolated material. The results of Experiment I are shown for comparison.

The results of Experiment 1, excluding the results for angles of 5° and 10°, are also indicated in Figure 3, for comparison. Because of the shorter retention interval in Experiment I, the errors should have been less than in Experiment II. The larger error evident in the Experiment-I results could be attributed to differences in the Ss involved, or to error. The fact that the slope of the line joining the two Experiment-I points is very similar to the best-fitting line through the Experiment-II points, however, indicates that the effects within Ss are consistent.

The effect of varying the position of interpolation within the retention interval is shown in Figure 4. In order to test this effect, separate

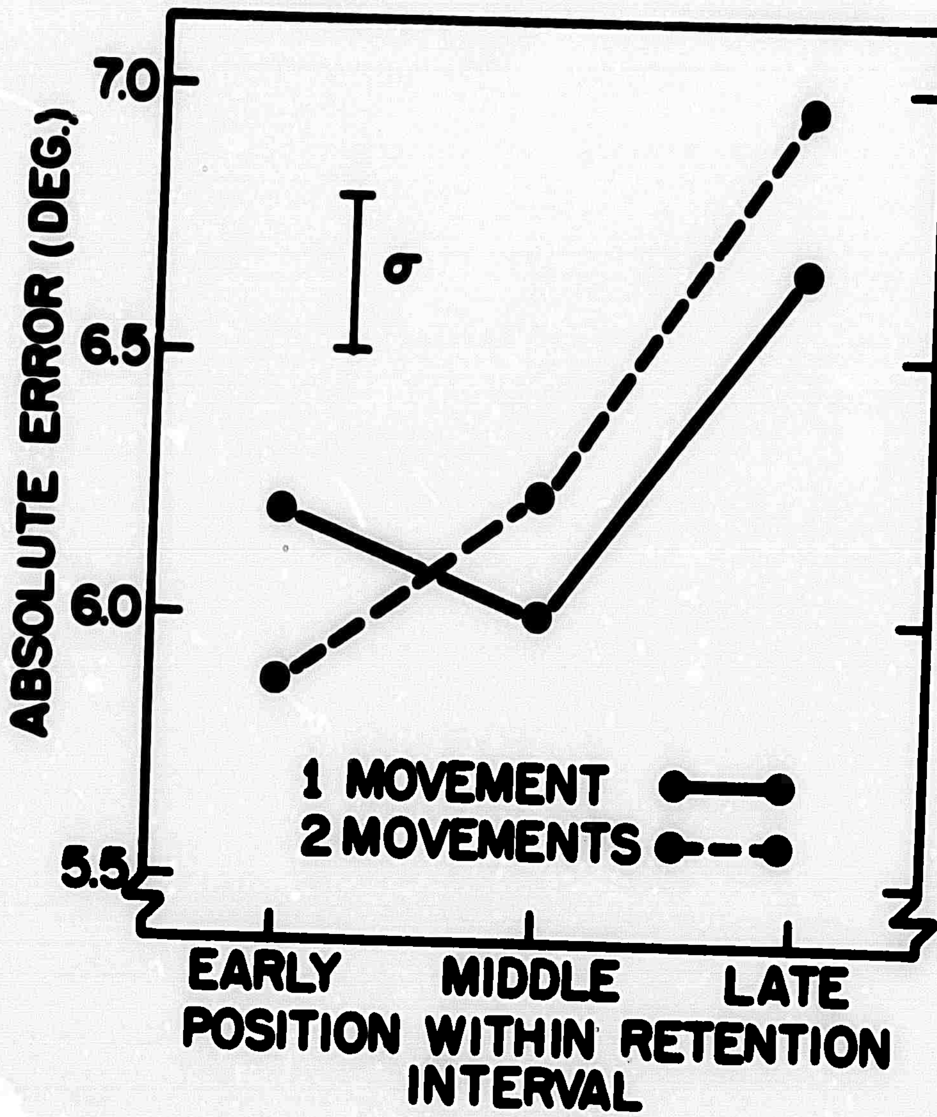

Fig. 4. Absolute error for one and two interpolated movements as a function of the position of the movements within the retention interval.

analyses of variance were carried out for one and for two interpolated movements. For the absolute error there was a significant effect of the position of the two interpolated movements, $\underline{F}(2,54) = 5.51$, $\underline{p} < .01$, but not for one movement, $\underline{F}(2,54) = 1.32$. These effects are shown in Figure 4. The size of a standard error, shown on the graph, indicates that no importance

should be attached to the crossover in effects between the early and middle positions. No interactions reached significance in either of these analyses.

Results for algebraic error indicated a marginal effect of amount of interpolated material, $F(1,189) = 3.38$, $.05 < p < .10$. Separate analyses for one and for two interpolated movements indicated that the effect of position on algebraic error was significant for one movement, $F(2,54) = 7.44$, $p < .01$, but not for two, $F(2,54) < 1$. However, the interaction of Subjects and Position was also significant for one item, $F(54,253) = 1.51$, $p < .05$. An attempt was made to discover whether the effect for each S was related to his overshooting tendency, but the rank-order correlation between these two measures was .07, indicating no relationship.

The variance of the algebraic errors was also examined. Table 5 shows the variances for the 8 treatment conditions, with the associated degrees of freedom. For the 8 variances involving one interpolated item (Conditions 2, 3 and 4), C = .38, and for two items (Conditions 5, 6 and 7) C = .41. Both of these are significant at $p < .05$. An examination of the individual variances indicates that, with the exception of Conditions 2 and 3, which are almost identical, there is an increase in the variance of the recall as the interpolated material moves towards the end of the retention interval.

The absolute error data from this experiment, as well as the variance data, suggest that two interpolated movements occurring in the first half of the retention interval have no effect on recall, while two movements

in the second half have as much effect as four movements filling the entire retention interval.

In the verbal literature, considerable importance is placed on the similarity between the retained and interpolated items, as there is much evidence that retention decreases as the similarity between the retained and interpolated material increases. In the present experiment, these similarity effects could be manifested in one of two ways. First, it might be expected that, up to a point, the greater the similarity between the interpolated and the target movement, the poorer would be recall. And second, there might be some relation between the angles recalled and the interfering items, which would be analagous to finding intrusions in the verbal situation.

These two possibilities were examined for the Condition-7 trials, where two interpolated movements appeared at the end of the retention interval. The first possibility was examined by calculating the regression of the absolute error on the absolute difference between the angle presented and each of the two interpolated angles. For the multiple regression, $F(2,318) = 1.39$, which is not significant. The associated multiple correlation coefficient was .09. The second possibility was examined by calculating the regression of the angle recalled on the two interpolated angles. Again, the result was not significant, $F(2,318) = .97$, with a multiple correlation coefficient of .08. Finally, the regression of absolute error on the sizes of the two interpolated angles was calculated, with the aim of examining the hypothesis that larger interpolated angles might produce larger errors, without regard to the sign of the error.

The regression was not significant, $\underline{F}(2,318) = .85$, with a multiple correlation of .07.

All these results indicate that there are no simple similarity relationships to be found in these data. This suggests that, either similarity effects do not affect retention in this situation, or we are not looking along the correct dimensions. If the size of the interpolated angle is not a relevant dimension, what others might be examined? One that readily comes to mind is the nature of the interpolated movement itself. It is known that an active movement similar to that being retained will cause an increase in forgetting. At the other extreme, neither the writing, nor the mental activity involved in an interpolated paper-and-pencil task has any effect. The next experiment examined this dimension, by interpolating movements which involved various components of the active movement which has been used thus far.

CHAPTER IV

EXPERIMENT III

In this experiment, the aim was to examine the effect of a range of different interpolated movements, each embodying a different set of the components which might be seen as comprising the retained movement. In the verbal situation, those dimensions of similarity which have been examined have been the acoustic or articulatory dimension, the semantic or linguistic dimension, and the dimension of formal similarity (e.g., consonants vs. vowels), as well as some others. The tacit assumption underlying such studies is that when verbal material is being remembered, only certain discriminating features of the item are selected and remembered. Since those features must be sufficient to reconstruct, or at least to mediate successful recognition, of the item retained, they will be chosen from dimensions along which verbal material varies, such as those mentioned above.

When Ss try to remember a number of items which have similar values on the selected dimensions, it is found that there is more forgetting than when those values differ widely. A number of different mechanisms for this forgetting have been proposed; but they need not concern us here. The point is that if a dimension can be found such that variation of the similarity of the retained and interpolated items along it affects retention, then that dimension has been used by S to remember the items. Information has then been obtained, albeit somewhat indirectly, about the way in which the items are encoded.

The first step in applying this strategy to the present motor situation is to isolate some relevant dimensions. It is difficult to find dimensions

on which many different values can be readily obtained, but there are a number which can be represented dichotomously. If the retained movement is envisioned as involving a number of discrete components, then it is possible to present interpolated items that involve only some of these components. The word "item" is used rather than "movement," as some of these items might only involve the decision-making or central components of the act of making a movement.

For the present experiment, the following four components were chosen as being both tractable and theoretically interesting. The first is the preparation or planning of the movement. Welford (1968, p. 140) suggests that brief movements such as the present discrete motor movement are "ballistic," in that they are initiated and carried out as a single unit, with S monitoring feedback only from the beginning and end of the movement. This is quite plausible when applied to the initial target movement, where S moves until he is brought to a sudden stop by the apparatus. It might not be so plausible in the case of a movement such as one used by Hollingworth (1909), where a bell rang at some point in the movement, signalling to S that he should stop as rapidly as possible.

This preparation component was manipulated by interpolating some items in which S was given the angle and direction to move through, but then told "DON'T MOVE" instead of "MOVE." This will be referred to as a Movement Preparation item. In the previous experiments, the angle and direction were displayed for 1 sec. prior to the "MOVE" signal. The same applied in this case, and it was again stressed that S should move as quickly as possible if "MOVE" appeared. It is therefore assumed that when "DON'T MOVE"

appears, S has used the prior 1-sec. period to prepare the movement, but the movement is not actually executed. If the interpolation of an item such as this results in considerable recall decrement, it means that S has used as one encoding dimension, perhaps an image of the distance to be moved through, or perhaps some transformation of the energy used to move that distance, or even an estimate of the time required to complete the movement.

The second component examined was the actual initiation of the movement, including whatever feedback might result from such initiation. The item which involved this component, the Movement Initiation item, also involved the first component mentioned above. In other words, S was asked to prepare and initiate the movement, but once he had moved 2° from the starting point, the apparatus took over and finished moving his arm through the displayed angle. If such an interpolated item had significantly more of a detrimental effect on recall than the first item to be mentioned, it would indicate that some aspect of the movement itself, specifically, the motor outflow, the feedback and whatever else may be involved in the initiation, is an important encoding dimension. The angle retained could be partly encoded, for example, in terms of the speed or amount of force involved in the initiation of the movement, but simply thinking about or otherwise preparing this initiation might not be sufficient. It may be that the additional components involved in the execution of this aspect must be performed before the interpolated item can in any way affect the trace of the retained item, or affect its recall.

In performing both of these interpolated items, S is exposed for at least 1 sec. to a display which indicates in degrees the extent of the

movement. If both of these two items are just as detrimental to recall as the complete movement used in the previous experiments, the display of this number may be responsible. The S may transform the number into his own measure of the extent of the movement, and this in itself may be sufficient to affect the retention of the original item. Less likely is the possibility that the original movement was transformed into a number, and that this interpolated number has the same effect as an interpolated number would have on the retention of a number in a verbal-learning experiment. This is not likely because a single number is retained very well over the time intervals involved in, say, Adams and Dijkstra's (1966) experiment, yet they found rapid forgetting of the movement over these intervals. Furthermore, the position effects found in the previous experiment would not be expected if verbal mediation were an important aspect of retention.

Whatever the mechanism of its operation, the possibility that such an effect may be important was checked by including an item identical to the second, except for the absence of the number indicating the movement extent. This will be referred to as Movement Initiation Without Display. For this item, S was required to initiate the movement, but he had no idea how far the machine would move his arm once the machine took over.

The final component which was examined involved all those aspects of the movement which are not concerned in the initiation and execution by S. This component will be termed the feedback component, since it involved some of the feedback associated with an active movement, but it would be best to define it operationally, in terms of the item used to measure

it, the Passive Movement item. The S saw the angle and direction display, but at the end of the 1-sec. period the word "RELAX" appeared on the screen, and the apparatus moved S's arm through the displayed angle. The S was therefore subjected to much of the feedback involved in making the complete movement. If an important aspect of the original movement which is retained is the feedback pattern it generates, then this item would be expected to have a significantly detrimental effect on recall.

Method

Design

In order to measure the effect of these items, a 12-sec. retention interval was completely filled with four examples of each item. The previous experiment indicated that two items at the end of the retention interval had almost as much effect as four items. Nevertheless, four items were used in this experiment rather than just two in order to obtain whatever small additional effect might result from the two early items.

The use of four Movement Preparation items in a single retention interval posed the problem that once S was exposed to the first of these, he would know that the remaining three would all be the same, and there would be no need for him to make the "preparation" that is assumed. It was therefore necessary to include a control condition, involving some examples of this item as well as some items in which S did actually have to complete the movement, exactly as in the previous two experiments. Such a complete movement will be referred to as an Active Movement item. Finally, two conditions were included for the sake of comparison. One involved a completely unfilled retention interval, and the other involved

a retention interval filled with four Active Movement items. Because of differences between Ss, the values obtained for these conditions in Experiment II could not be used in evaluating the results of this experiment. There were therefore seven basic conditions in which the retention intervals were filled as follows.

1. Four Movement Preparation items, in which S was prepared to move, but was told "DON'T MOVE" at the last moment.

2. Four Movement Initiation items, in which S initiated the movement, but once he had moved 2° the apparatus took over and completed the movement as displayed.

3. Four Movement Initiation Without Display items, each identical to a Movement Initiation item, but with no angle displayed.

4. Four Passive Movement items, in which S was told to "RELAX" while the apparatus drove his arm through the entire movement.

5. Four Active Movement items, exactly as in Condition 8 of Experiment II.

6. A completely unfilled retention interval, exactly as in Condition 1 of Experiment II.

7. This was a control condition, in which Active Movement and Movement Preparation items were mixed.

The aim in constructing these Condition-7 trials was to make S as unsure as possible, particularly on the last two items of the retention interval, whether each item would be an Active Movement or a Movement Preparation item. Since it would take too many control trials to ensure that all the transitional probabilities were equal, it was decided to

concentrate on the last two items of the retention interval, since, from Experiment II, these were where the greatest effect would be produced. The control trials were therefore divided into three types. In the first type, the first item was a Movement Preparation item and the last three were Active Movement items. This sequence can be represented as PMMM. In the second, the sequence was PPMM, and in the fourth, PPPM. On the very first item of each retention interval, if S saw a number and an arrow, he could not tell whether that item would be Movement Preparation or Active or Passive Movement. The item was only identified once the words "DON'T MOVE," "RELAX," or "MOVE" appeared. If the first item was Movement Preparation, the probability that the next would also be Movement Preparation was .83. If the first two were Movement Preparation, the third was of the same type with a probability of .80, and if the first three were Movement Preparation, the probability of the last one's being so was .75. The maximum uncertainty was therefore associated with the last position.

All the manipulations were again within Ss. Each S received 84 trials, made up of 6 angles x 7 conditions x 2 replications. The angles were the same as in Experiment II, and again, within each S, presentation and recall for any given angle size were always in the same direction. Across the 32 Ss, however, each presentation direction occurred equally often with each recall direction, and each of these pairs in turn occurred equally often with each angle.

The 84 trials were again arranged in six arbitrary blocks and the trials of one replication were all presented before the second was begun. The same arrangements of the six blocks were used to present a single list

to four Ss. Apart from this, the trials were, as before, presented randomly. Within each trial, the restrictions on choosing the finishing points for each movement were as in the first two experiments. For Movement Preparation items, however, the fact that S did not actually move had to be taken into account. Where a number of such items occurred consecutively, the "finishing point" for each was chosen independently and randomly for each occurrence.

Three practice periods were given for this experiment. The first involved only Conditions 1, 5, 6 and 7, i.e., only Movement Preparation and Active Movement items, and rest trials. When S had completed five consecutive trials successfully, he was given the second practice list, which involved only Conditions 2, 3 and 6. After again successfully completing five consecutive trials, the third practice period followed. This was similar to the second practice period in Experiments I and II. The proportion of trials of each condition was as in the main part of the experiment, and feedback was given. This session was terminated, as before, when S had reached the 2° criterion on three trials, or when he had completed ten trials, whichever took longer.

The only changes in instructions from the previous experiment related to the new interpolated items. At the first practice period S was told that the word "ERROR" would appear if he moved when "DON'T MOVE" was the instruction. At the second practice period, the importance of relaxing and letting the apparatus do the work when the word "RELAX" appeared was stressed, and instructions were given about Conditions 2 and 3. Details of these instructions are in Appendix A.

Procedure

Changes in the procedure from the previous experiments were relevant to the new items used. If S moved when "DON'T MOVE" appeared for a Movement Preparation item, the error signal was "ERROR." If S resisted during any of the conditions involving passive movement, so that the clutch slipped and the lever did not reach the finishing point by the time the 3 sec. was up, the error signal "YOU MUST RELAX" was displayed. A Movement Initiation item was signalled by the appearance of a diamond around the number indicating the size of the angle, for a Movement Initiation Without Display item, the diamond appeared, but there was no number inside it.

Subjects

There were 32 right-handed male Ss drawn from the same source as for the previous experiments. None of the Ss had participated in the earlier experiments. Their base pay and bonus was as in Experiment I.

Results and Discussion

Overall Analysis

Of the 2688 trials in the experiment, a total of 101, or 3.6%, were missing because of apparatus failures. These were estimated, as in Experiment II, by replacing each with the corresponding value from the other replication. Degrees of freedom were reduced where appropriate.

In an analysis of variance on the absolute errors, two of the main effects were significant; Angles, $F(5,155) = 10.74$, $p < .001$, and Treatment Conditions, $F(6,186) = 2.34$, $p < .05$. The Treatment-Condition effects was subjected to an F test, since no contrasts were planned on the

means. There were two significant interactions, Subjects x Angles, $F(155, 829) = 2.06$, $p < .001$, and Treatment x Angles, $F(30,829) = 2.78$, $p < .001$, for which the explanations are as previously offered. For the algebraic error, the same main effects were significant. For the Treatment-Conditions effect, $F(6,186) = 8.27$, and for the Angles effect, $F(5,155) = 32.40$, all of these being at $p < .001$. There were two significant interactions, Subjects x Practice, $F(31,829) = 1.84$, $p < .01$, and Subjects x Angles, $F(155,829) = 2.98$, $p < .001$.

The means for the Angles effect again indicated undershooting for the three largest angles, and overshooting for the three smallest. The regularity of this effect can be seen in Figure 5, where the mean algebraic error is shown for the angles in each of the three experiments.

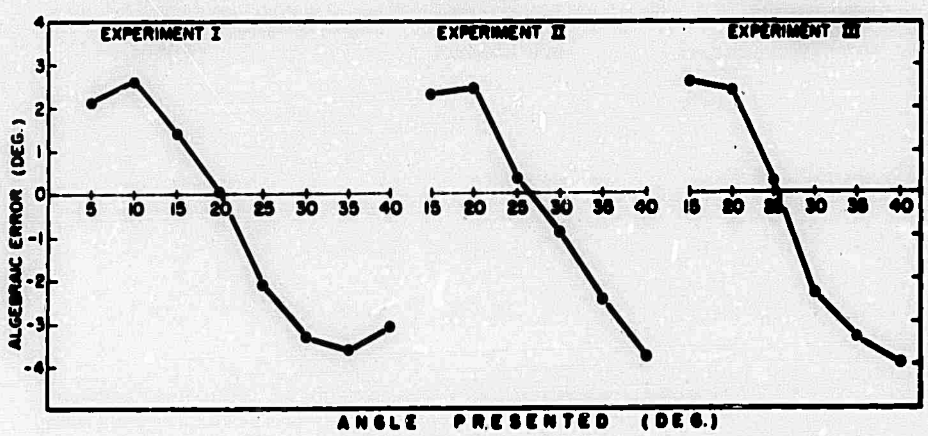

Fig. 5. Algebraic error as a function of target angle size for Experiments I, II and III.

An analysis of variance was also carried out on the latencies for recall. These were measured from the time the word "RECALL" appeared, to the time when S moved 2°. A square-root transformation was carried out on the data. All the main effects were significant: Subjects, $F(31,829) = 34.67$, $p < .001$, Treatment Conditions, $F(6,186) = 10.21$, $p < .001$, Practice, $F(1,31) = 18.47$, $p < .001$, and Angles, $F(4,155) = 2.78$, $p < .05$. There were, in addition, three significant interactions with Subjects: Subjects x Treatment Conditions, $F(186,829) = 3.65$, Subjects x Practice, $F(31,829) = 3.64$, and Subjects x Angles, $F(155,829) = 1.93$, all at $p < .001$.

The Practice effect was such that the mean for the first half was 1110 msec., and for the second half, 1052 msec. Even though there was no change in accuracy over the two halves, Ss did react slightly faster to the "RECALL" signal. These means, as well as all other latency figures, are the squares of the means obtained after a square-root transformation.

The Angle effect, for which means are given in Table 7, is an enigma, as there is no obvious reason why Ss should react faster when recalling

TABLE 7

MEAN ABSOLUTE AND ALGEBRAIC ERRORS (IN DEG.), AND MEAN LATENCIES (IN MSEC.) FOR THE ANGLE EFFECT: EXPERIMENT III.

	Angle					
	15°	20°	25°	30°	35°	40°
Absolute Error	5.11	5.12	5.08	6.08	6.82	7.47
Algebraic Error	2.50	2.31	.29	-2.32	-3.31	-3.95
Latency	1096	1111	1086	1057	1065	1069

some angles than others. A possible explanation is suggested by the fact that the latencies for the three smallest angles are all larger than those for the largest ones. It may be that since recall is under a time restriction, and since the larger angles will take longer to complete than the smaller ones, S reacts faster to the larger angles to be sure of completing them in time.

Treatment Effects

Figure 6 shows the Treatment Condition means for the absolute error. Since the Treatment Condition means were not on any type of scale, and

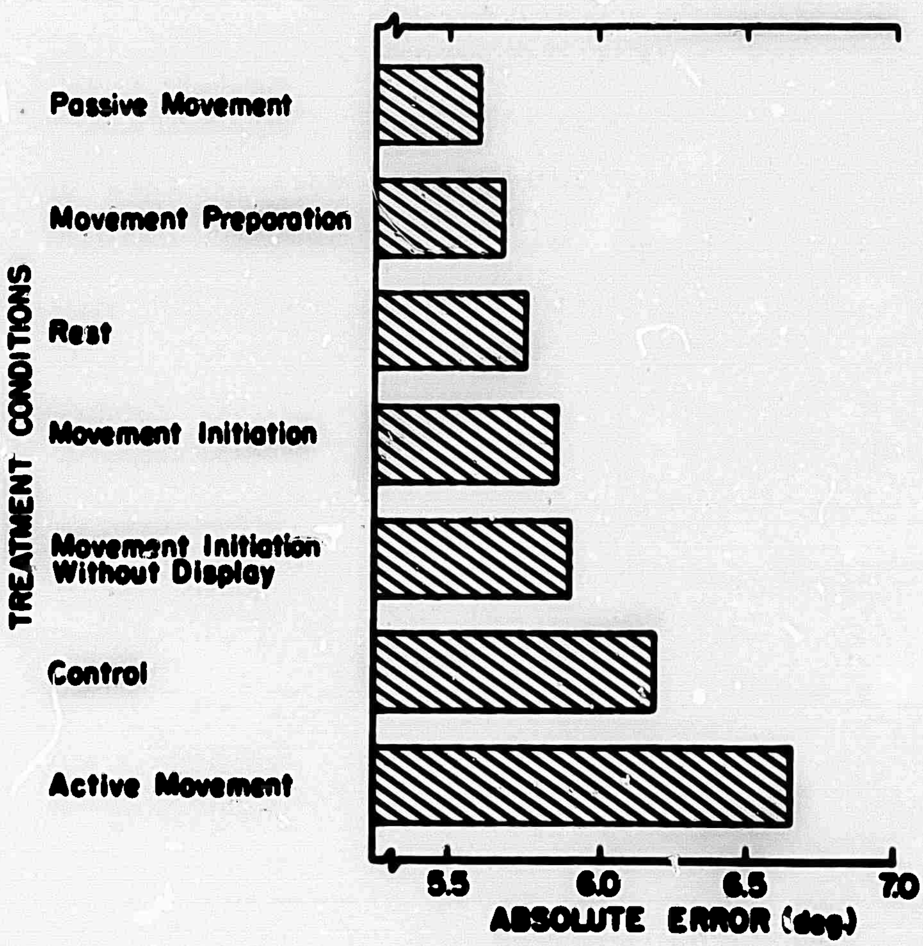

Fig. 6. Absolute error for the seven treatment conditions.

there were no specific prior hypotheses about their order, posterior comparisons were carried out using Duncan's New Multiple Range test (Duncan, 1955) to examine all pairwise comparisons among the means.

For the absolute error, the results of Duncan's test can be summarized schematically as follows:

4 1 6 2 3 7 5

Treatment means underlined by a common line do not differ from each other, whereas those not underlined by a common line do differ, the significance level being 5% or better. For ease of comparison, the order of the conditions in Figure 6 is the same as in Duncan's test above.

It is clear that Condition 5 (Active Movement) produced recall which was significantly worse than almost all the other conditions. The differences between the means for Condition 3 (Movement Initiation Without Angle) and Condition 5 was .737°, while the difference required for significance at the 5% level was .745°. This suggests that Conditions 2 and 3 (the two Movement Initiation conditions), while not significantly different from each other, have together significantly less of an effect than Condition 5 (Active Movement). Removing from the display of Condition 2 (Movement Initiation) the number which tells S how far he will be moving, clearly has no effect on the results. Similarly, simply asking S to prepare a movement without his actually making one does not have a significantly detrimental effect on recall. It may be argued that the transitional probabilities associated with the occurrence of an Active Movement item after a Movement Preparation item are not high enough to make S seriously prepare a movement. Even if this were so, it is hard to imagine

that S would not make such a preparation on at least some of the trials. And if this preparation had any effect, even if it were not sufficient to produce a significant effect under these conditions, it would at least raise the mean error above that for Condition 6, the rest condition. As the results show, both Condition 1 (Movement Preparation) and Condition 4 (Passive Movement) produced mean errors actually slightly below that of Condition 6.

The interpolation of passive movements, as shown by the results of Condition 4, obviously has no detrimental effect on recall. The import of this is that S does not remember the angle he moves through in terms of any transformation of the feedback it generates. This is in keeping with the physiological evidence, cited earlier, indicating that a response can be learned without kinaesthetic feedback, and that a consistent response can be executed without such feedback.

As has already been suggested, while the two Movement Initiation conditions together appear to have significantly less effect than the Active Movement condition, they do not differ significantly from the Rest condition. The fact that these two means are the largest of those conditions not involving any complete movements, however, suggests that the small amount of active movement they involved may have had a small effect on retention. This supports the view that the important variable affecting retention is the amount of active movement made by S, since neither passive movement nor movement preparation has any effect. This in turn leads to the conclusion that the movement amplitude is retained in terms of the motor outflow required to produce that amplitude and that feedback patterns and mental images of the movement play no important part in this retention.

The mean for Condition 7 (Control) is almost half-way between that of Condition 6 (Rest) and Condition 5 (Active Movement). This reflects the combination of Movement Preparation, which has no effect by itself, with Active Movement, which is responsible for the largest effect. The three sub-conditions which went to make up the control condition were represented as PPPM, PPMM, and PMMM, this being the ordering of the Preparation and Active Movement items within the retention interval. The mean absolute error for each of these three sub-conditions was 5.74°, 6.25° and 6.51° respectively, indicating the progressive increase in effect as the number of Active Movement items increases. The additional effect of adding an Active Movement item in the second position is less than that of adding one in the third position, which is in keeping with the position effect demonstrated in Experiment II.

In Table 8 the variances for the seven treatment conditions are shown. They are in the same rank order as the mean absolute errors, except for

TABLE 8

VARIANCES FOR THE SEVEN TREATMENT CONDITIONS: EXPERIMENT III.

Treatment Condition	Variance	d.f.
1. Movement Preparation	47.35	367
2. Movement Initiation	77.27	372
3. Movement Initiation Without Display	52.90	375
4. Passive Movement	61.44	364
5. Active Movement	51.98	366
6. Rest	55.87	376
7. Control	57.79	367

Condition 6 (Rest), which has the smallest variance. Figure 7 shows the mean algebraic errors for the treatment conditions. The application of Duncan's test gave the following results, at the 5% significance level.

4 5 3 1 7 2 6

The main conclusion from this test is that Condition 6 (Rest) produced significantly more undershooting than all of the other conditions.

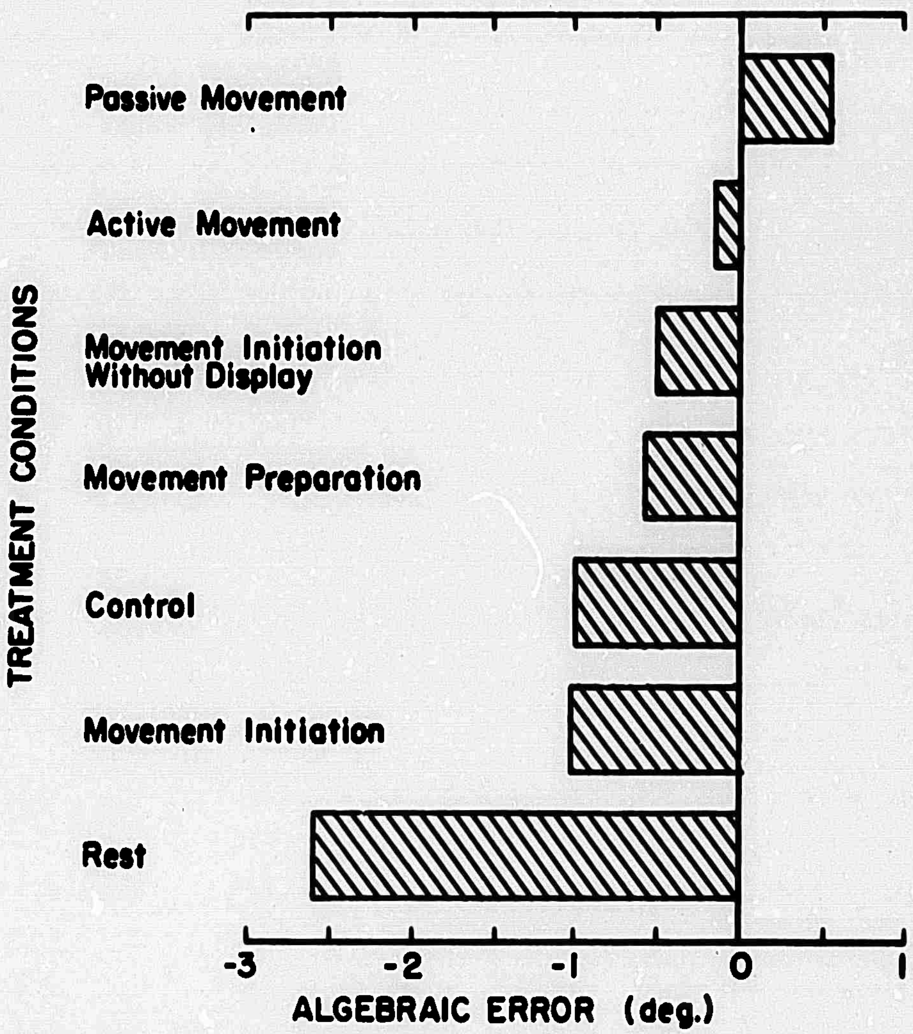

Fig. 7. Algebraic error for the seven treatment conditions.

The recall latencies for the treatment conditions are shown in Figure 8, and for these data, Duncan's test gave the following results, at the 5% level.

7 4 5 1 2 3 6

Condition 6 (Rest) resulted in a faster RT than all the other conditions. The RT for Condition 7 (Control), while slower than the four fastest conditions, was not significantly different from Conditions 4 and 5 (Passive and Active Movement).

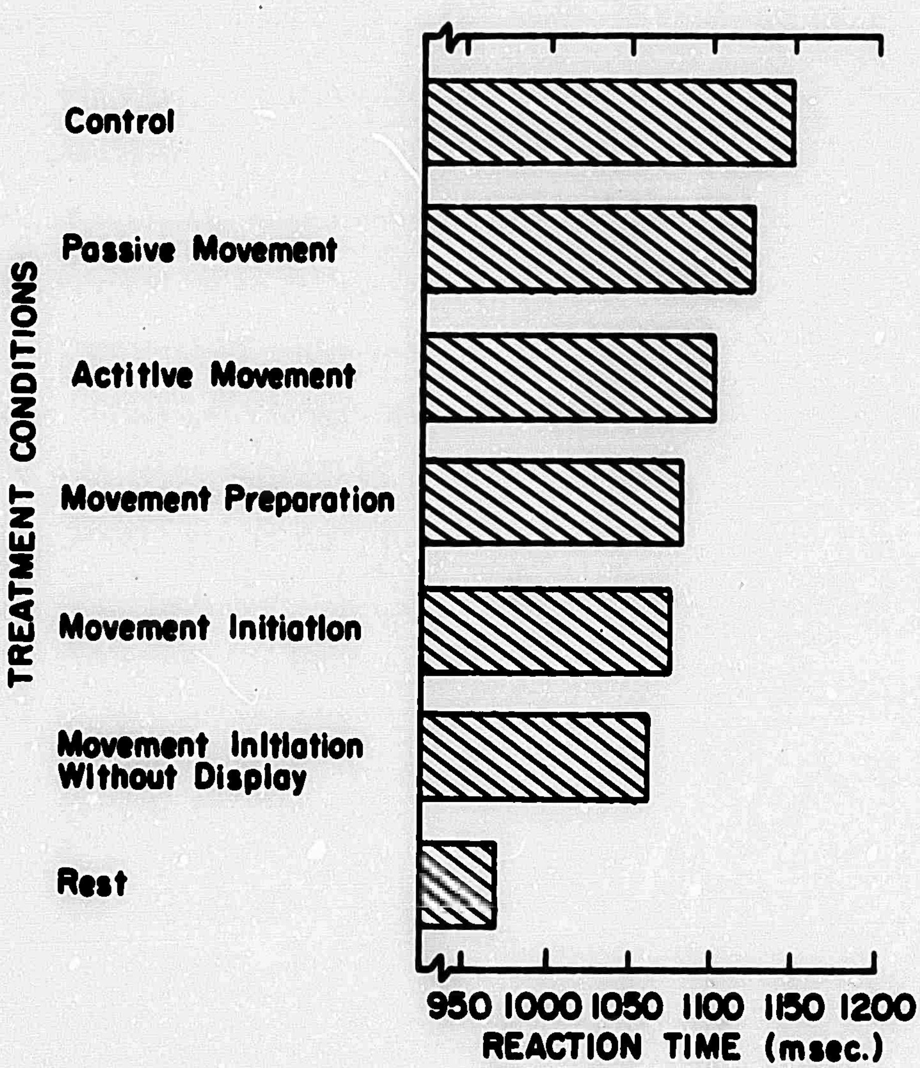

Fig. 8. Response latency for the seven treatment conditions.

In general, it appears that interpolating anything results in an increased RT. This may simply be a result of the visual stimulation which occurs when any item is interpolated, in comparison to the Rest condition, where the screen was blank the whole time. The RT difference that is involved is in the order of 100 msec., which could result from S's having to switch attention to the recall task from whatever material was interpolated.

One possible reason for the position effect found in Experiment II might be that an interpolated item at the end of the retention interval could have prevented S from preparing his recall, and that because of the time constraint for recall, the effect was to reduce accuracy. Evidence against this hypothesis can be obtained by comparing the RT and the absolute error data for each condition. If the hypothesis were true, those conditions which resulted in the largest absolute error should also have had the longest RT's, yet Condition 4 (Passive Movement), which has the smallest absolute error, has one of the largest mean RT's. A more conclusive test of this hypothesis was carried out by examining the regression of accuracy on the RT across all conditions. For the regression coefficient, $F(1,\infty) = 3.61$, $.05 < p < .01$, with an associated correlation coefficient of $-.02$. This makes it clear that accuracy and RT effects are independent in these experiments.

CHAPTER V

GENERAL DISCUSSION

The main aim of the third experiment in this series was to shed some light on the way in which a movement amplitude, of the nature presented in these experiments, is encoded. Although S is asked to remember an amplitude, rather than absolute positions, it may still be possible for S to remember the starting and finishing positions for each movement, and, with a little algebra, to calculate the appropriate finishing position when he is given a new starting position. Evidence from previous studies, and from the results of Experiment I, has already been given against this view.

An alternative view is that the movement is represented as an integral force or velocity over time. Although these aspects may play a part, there is evidence that they are not the whole story. Woodworth (1899) found that a given line drawn with a light force can be reproduced quite well with a heavy force, or even if simply delimited with two dots. And the fact that a given line can be reproduced accurately if made with a different limb, or in a different orientation, also speaks against this. Nevertheless, as each of the conditions of the original presentation was changed, Woodworth found that performance deteriorated to some extent, indicating that these conditions form some part of the complex representation of the movement.

There is some suggestion in the literature that the movement is represented as an image. Posner and Konick (1966a) entertain only two alternatives for the encoding of their motor movement, which are that it is encoded either as an image or with verbal labels. These authors present evidence against

the use of verbal labels, which leaves them with the image construct. Evidence that a simple visual image is not the main representation, however, comes from the lack of effect of Condition 1 (Movement Preparation) in Experiment III. On the other hand, to be fair, the actual form of the image is not specified by these authors, and it may well be possible that a kinaesthetic "image" incorporates much more information than a visual image, but if the word "image" is used in this way, its meaning has been changed somewhat. The information that would have to be included in such an image would come mainly from the original motor output, but perhaps also from joint, muscle and tendon receptors.

While it is clear that no one source of information is likely to be the sole source of the encoded representation of a motor movement, there are strong suggestions as to the most important one. The results of Experiment III indicate that interpolated passive movement does not affect retention at all. Together with previous evidence, this suggests that the motor outflow produced in the original performance of the movement is one of the most important sources of information. This is further supported by the trend evident in Experiment III, where the amount of forgetting is directly related to the amount of motor output produced during the retention interval.

Another major question on which these experiments can shed some light is that of what happens to the representation of the movement as it is forgotten. There is something analagous to decay, since forgetting occurs over time when there is an unfilled retention interval, and when 3 min. separates trials (Adams and Dijkstra, 1966). There is also an interference

effect, dependent on gross similarity between the retained movement and the interpolated item, as shown by present and previous results.

The results of Experiment II also show an effect which is quite different from that found in the verbal situation. In the present case, the later the material is interpolated in the retention interval, the worse is recall, whereas with verbal material, recall appears to be worse with earlier interpolation. The effect of the interpolation therefore seems to be proactive on the recall process, rather than retroactive on the original learning. It cannot be a matter of interference during storage, or of accelerated decay resulting from the presence of the interpolated items, as the decrement in recall results from conditions which minimize these factors.

There are several alternative explanations of these results. One is that they arise from interference with the recall process resulting from temporal proximity of the interpolated movement. The fact that S has just made a movement leaves him in something analagous to a refractory state, in which the organization of the next movement, the recall, is impaired. An objection to this is that all the previous evidence on refractory-period phenomena suggests that it may last up to .5 sec., and certainly not over 1 sec. (Welford, 1968, p. 120). In the present experiment, a refractory period lasting up to 1 sec. may have been sufficient to impair recall, since only 3 sec. were allowed for the recall to be completed. In the experiments of Williams et al. (1969), however, it is implied that Ss had as long as they wished to complete the recall, yet there was still a decrement resulting from interpolated movements. Furthermore, analyses relating RT to accuracy in Experiment III suggest that there is no relation

between the two, whereas it is unlikely that a refractory-period phenomenon would cause an increased error without also causing an increased RT.

Several other explanations derive from the steep forgetting curves, shown by Posner and Konick (1966a) and Adams and Dijkstra (1966) for a discrete motor movement, even when there is no interpolated material of any kind. In the case of Adams and Dijkstra, the "half life" of the item was about 20 sec., while it was about 5 sec. in the Posner and Konick study. It would follow that, if the decay is an exponential process, the ratio of the strength of the interpolated item to that of the retained item would be greater the later the interpolated item is presented.

There are a number of ways in which the observed effects could result from relative strength notions such as this. One possible mechanism is that when the interpolated item occurs early in the retention interval, the strength of the target item is still so great that the trace of the interpolated item, which does not have to be retained, is obliterated. Combined with this could be the fact that when the interpolated item occurs late in the retention interval, its strength is such, relative to the strength of the already-decayed target item, that accurate recall of the target is difficult.

Another possible mechanism which could be responsible for the lack of effect of the items interpolated early in the retention interval is that Ss may be able to actively forget such items, since they do not have to be retained. There is evidence (Bjork, LaBerge & Legrand, 1968) that with verbal material Ss can actively forget items they know they do not have to retain. If this process takes some time to occur, it is possible

that items interpolated early could be forgotten by this process, but not items interpolated late.

These two explanations are similar in that both account for the observed effects as resulting from the forgetting of interpolated items presented early in the retention interval. In the first case, the forgetting is the result of a decay process which S could not arrest even if he were trying to retain the item, while in the second, it is an active process on S's part, a process which takes some time to initiate. A test between these two positions could be arranged by having S retain the interpolated items, and then telling him to forget them just prior to the recall of the target item, but with an interval between the "forget" instruction and the recall which is long enough for the forgetting to take place. As an initial approximation, 3 sec. should be sufficient for this. If there were still a tendency for items occurring later in the retention interval to produce a greater decrement in retention, support would be given to the notion that spontaneous decay alone is responsible. Should all items have little or no effect, this would support the notion that S has actively forgotten the interpolated movements.

Both of these proposed explanations, which rely on relative-strength notions, are versions of a response competition explanation. The effectiveness of the interference is a function of the relative strengths of the traces of the competing item and the retained item at the time of recall. In the verbal learning literature, there is a considerable body of evidence against such a position (e.g., Posner and Konick, 1966b; Conrad, 1967; Martin, 1969). This evidence stems largely from the fact that the number of instrusion

errors is not perfectly related to the amount of forgetting of the original list, and that when both responses in an A-B A-C paradigm are called for, the probabilities of the recall of B and C are independent.

In the present situation, nothing analagous to intrusion errors were found when the sizes of recalled angles were compared to the sizes of interpolated angles. This suggests that with motor material, a simple response-competition explanation will not account for the obtained position effect. Another explanation which will not do is any version of disruption of consolidation. Since interference is worse when it occurs later, its effect cannot be due to disruption of consolidation, as it is central to this notion that the trace is most labile immediately after the event, and that interference should therefore have its strongest effects when it occurs immediately after the presentation. An explanation in terms of difficulty in differentiating the two responses is also ruled out, since such an explanation demands that recall performance should decrease as the time since the presentation of the interpolated item increases, the opposite of what is found.

In looking for an explanation of the position effect we are therefore left with attention focused on the major difference between verbal and motor retention, the fact that there is a rapid, apparently spontaneous, decay of the motor trace. The effect of this is to produce differences in trace strengths between target and interpolated items at the time of recall, differences which could be enhanced by effects on the interpolated material of the original presentation, or by active forgetting of the interpolated material. Although obvious intrusion errors were not found,

these differing relative strengths could be responsible for the obtained results in a more general way. It could be the case that recall is not worse because S has made a movement of a particular size just before recall, but because he has made any movement at all. The results of Experiment III indicate that it is interpolated motor output which causes the decrement, while the results of Experiment III suggest that the closer the interpolated movements occur to recall, the more adversely they will affect that recall. It is not possible to be more specific than this at present, but even in the verbal situation, Martin (1969) points out that no good explanation of retroactive interference effects exists.

In connection with the question of what happens to the trace of a motor act as it is forgotten, Pepper and Herman (1970) direct their attention to effects on algebraic errors. In a number of studies of the retention of a movement extent, including a reexamination of data by Posner (1967), who does not quote algebraic errors, Pepper and Herman find a negative time error, i.e., an undershooting, which increases with time. Other studies which support this finding are Adams and Dijkstra (1966) and Stelmach (1969). Pepper and Herman account for this in terms of the traditional fading-trace theory.

A second finding with respect to the algebraic effect is that any interpolated material tends to result in a more positive error. The results of all the present experiments support this finding. In the first experiment, the rest condition resulted in an undershooting of 1° to 3°, while the mean for the interpolated-movement conditions was close to zero. In Experiment II, a slight undershooting of about 1° is reduced to zero with

interpolated material, although the position effects in this case are somewhat confusing. Finally, in Experiment III, a mean algebraic error of about -2.5° is raised to between -1° and .5° by the interpolation of any material. The large between-S differences and the many interactions make it quite clear that these are only average effects, nevertheless, they appear to be quite consistent. Pepper and Herman offer an explanation in terms of the distracting effects of the interpolated materials. They give evidence that any such distraction will cause an increase in muscle tension, which may augment the fading trace. The S, when recalling, will then be attempting to match a larger trace, and he will therefore give a raised algebraic error. No place is given in their account, however, for the increase in absolute error which has been found in the present experiments, as well as in previous ones. Some importance should also be placed on the present finding that the variance of the algebraic errors mirrors very closely the absolute error. It is quite possible for the absolute error to increase without a corresponding increase in the variance. The fact of this variance increase suggests that S is trying to match a trace which is not only "shrinking" (which would be a less ambiguous term than "fading"), but also getting dimmer in some sense, so that it is reproduced less accurately.

This suggestion is strongly supported by the effect of angles on the algebraic error, as shown in Figure 5. The finding that the smaller amplitudes in a series are overestimated and the larger ones underestimated is not new; it was explored at length by Hollingworth (1909). It indicates, however, that Ss tend to err toward the mean when making their recall. This could be taken as strong evidence that the tendency for the "shrinking"

trace to move toward the mean angle presented is much stronger than its tendency, whatever its original size, to shrink absolutely. However, it is much more likely that this represents a tendency for S to guess at the mean whenever he is in doubt as to the size of the angle presented. This effect is obviously much stronger than any absolute shrinkage. If it were not, we would expect the negative time error to be present for each angle taken separately, and not just for the mean of all the angles. It therefore seems clear that whatever the effects of interpolated material on the algebraic error, there is a strong tendency for forgetting, whether it be a result of time, as in previous experiments, or of interpolated material, as in the present ones, to cause the representation of the movement to fade as well as to shrink. The results of the present experiments make it clear that this tendency must be included if all the results are to be explained.

Summary and Conclusions

This series of experiments has attempted to shed some light on the encoding and forgetting of discrete motor movements. The techniques that have been used involved the interpolation of motor movements or sub-movements in the interval during which a discrete motor movement is being retained.

The major findings of Experiment I are that three movements interpolated in a 9-sec. retention interval are sufficient to produce a recall decrement, and that recall accuracy is not significantly affected by whether or not the recall is made over the same path as the original presentation. A tendency was also found for movements made to the right, or away from the body, to be better retained.

In Experiment II, both the amount and position of interpolated material was varied. As expected, the effect of amount was such that recall decreased as the amount of interpolated material increased. However, the effect of position of the material within the retention interval was strong, with material occuring late in the retention interval producing worse recall. This is in contrast to the verbal situation were there is a tendency for material presented early in the retention interval to have the most detrimental effect on recall. The effect of the interpolated material on the motor item must therefore occur at recall, and is not a matter of interference with a trace, or of accelerated decay of that trace during storage. However, although this major difference appears between the motor and the verbal situation, there is the similarity which results from the fact that an interpolated motor item of the same gross nature as the item to be remembered does adversely affect recall.

This finding was examined further in Experiment III, where the motor movement was broken down into subunits, some of which were presented separately during the retention interval. Interpolated items which involved only feedback components, or only components which are involved in the preparation of the movement, were not found to interfere. Interference was found to be a function only of the amount of motor outflow produced during the retention interval. It was therefore concluded that since motor outflow is the only component to affect the recall, the motor outflow component of the original movement is an important encoding dimension for the retention of that movement.

Finally, the concept of a shrinking trace was discussed. In the present experiments, forgetting is manifested as an increase in the variance of recall as well as a change in its constant error. This indicates that forgetting must be the result of a dimming of the trace, and not only a result of a change in its size or extent.

APPENDIX A

INSTRUCTIONS TO SUBJECTS

The S was seated in the chair and his arm fitted to the apparatus so that the tip of each elbow was always in a constant position. He was asked to move the lever through the limits of its travel, and was shown how to rest his arm in his lap between trials, and how to find the lever without looking for it visually. He was then given the following instructions.

Experiment I.--"This experiment is divided into a fairly large number of discrete trials, each lasting about 30 sec. During each trial you will move your arm through an angle, and then, about 10 sec. later, you will try to reproduce that movement. Instructions will appear on the screen in front of you; watch it the whole time, don't try to look down at your elbow.

"Each trial will begin with the words 'GRASP LEVER' appearing on the screen. This is a signal for you to find the lever, grasp the handle and hold it steady, as I showed you. Then the words 'MOVE AND REMEMBER' will appear, with an arrow underneath them. On this signal, move the lever smoothly, in the direction of the arrow, until it stops. Your arm has now moved through an angle or a distance, however you wish to think of it, and it is this angle which you will have to reproduce about 10 sec. later. During this 10-sec. period a number of movements may take place, as I will explain in a moment. You will then see the word 'RECALL' on the screen, with an arrow beneath it. This is a signal for you to try and move your arm through the same angle it moved through when you saw 'MOVE AND REMEMBER' about 10 sec. earlier. I want to stress that it's the angle or distance

that counts; you are not being asked to move your arm back to any particular position. No matter where your arm is when 'RECALL' appears, move it from that position through the same angle you moved it through when you saw 'MOVE AND REMEMBER.'

"During the intervening 10-sec. period, the screen may remain blank, in which case just keep your arm still for that period. Otherwise, you may be asked to make a number of movements. Whenever you see a number on the screen, with an arrow underneath it, prepare to move that many degrees in the direction of the arrow, but don't move until the word 'MOVE' appears above the number.[1] When the word 'MOVE' does appear, move as quickly as possible. When the word 'RECALL' appears, try to reproduce the original angle of movement, as I explained earlier. The trial ends with the word 'REST', which is a signal for you to rest your arm in front of you, as I showed you. During the interval between trials, the lever will automatically be reset to a new position.

"During a trial, anytime you make a mistake an appropriate message will appear on the screen. The messages are fairly self-explanatory, but I'll just run through them. 'WRONG DIRECTION' and 'KEEP STILL' are obvious. 'DON'T ANTICIPATE' appears if you move before you are told to in the intervening movements. You only have about 2 sec. to complete each movement; if you exceed this limit 'TOO SLOW' will appear. If, for any reason, you almost reach the limit of the lever's travel, 'TOO FAR' will appear.[2] Immediately after any of these errors, 'REST' will appear and the next trial will follow.

"Finally, each movement you make must be smooth and deliberate, because as far as the computer is concerned your movement is over once you come to a stop. This means you can't make any corrections after stopping the first time.

"We will have some practice before beginning the experiment, and I'll be here to answer any questions during the practice. Do you have any questions now?"

After the first practice period, these instructions followed.[3]

"Now that you understand how the experiment works, let me tell you what we are measuring. Our main concern is with your ability to reproduce the initial angle correctly. However, we are also taking many measurements on the intervening movements; the time it takes you to begin moving after 'MOVE' appears, and your time to complete the movement, as well as your accuracy in making the required estimations. We are concerned with how well you can make these estimations under conditions where you are trying to remember another movement.

"Your pay for the experiment will be $2.25 plus a bonus of 3 cents each time your recall is within 2° of the angle presented. To give you some idea of how you are doing, for the next practice period only, I'll tell you through this intercom what your error is in degrees each time you recall."[4]

After this practice period, S was brought out of the experimental room for a few minutes while E prepared for the experimental session. The S was told that the experiment would last about 45 min. and that there would be a short rest half-way through. He was then seated and told to put on the headphones.

Experiment II.--The instructions were the same as for Experiment I, except that the retention interval was described as being about 15 sec. instead of 10, and the main experiment was described as taking about an hour instead of 45 min.

Experiment III.--The instructions were largely the same as for Experiment II, with the following major insertions and changes. The numbers refer to the superscripts in the above instructions, which indicate the relevant points of insertion or change.

1. Insert "You must wait until the instruction appears, because sometimes the words will be 'DON'T MOVE,' in which case, of course, you will remain still."

2. Insert "and if, in one of the intervening movements, you move when 'DON'T MOVE' is displayed, the word 'ERROR' will appear."

3. An additional practice period was given at this point, with the following instructions.

"So far, the intervening movements have included only those with 'MOVE' or 'DON'T MOVE' above the angle. There are two more basic types which you will have some practice with now. For the first, instead of 'MOVE,' the word 'RELAX' will appear. In this case, just relax and the lever will move your arm through the angle displayed. Don't resist the movement, but don't help it either. In the other type, the number will appear with a diamond-shaped box around it. The command will still be 'MOVE' but all you have to do is initiate the movement. As soon as you start moving, the machine will take over and finish it for you. Sometimes the diamond will appear without a number within it. Treat this just as if there were

some number there. Any questions? Now we will have some practice with these trials."

4. The following insertion was made in the instructions for the final practice period.

"During this practice period, the various types of trials will all occur in the same proportions as in the main experiment."

APPENDIX B

TABLED VALUES FOR DATA SHOWN

IN FIGURES 3, 4, 6, 7 and 8.

TABLE 1

ABSOLUTE ERROR (IN DEG.) FOR THE EIGHT TREATMENT

CONDITIONS: EXPERIMENT II (FIGURES 3 & 4).

	Treatment Condition							
	1	2	3	4	5	6	7	8
Absolute Error	6.02	6.20	6.00	6.66	5.88	6.23	6.96	7.14

TABLE 2

ABSOLUTE ERROR (IN DEG.) FOR THE SEVEN TREATMENT

CONDITIONS: EXPERIMENT III (FIGURE 6).

	Treatment Condition						
	1	2	3	4	5	6	7
Absolute Error	5.68	5.86	5.91	5.60	6.65	5.76	6.17

TABLE 3

ALGEBRAIC ERROR (IN DEG.) FOR THE SEVEN TREATMENT CONDITIONS: EXPERIMENT III (FIGURE 7).

	Treatment Condition						
	1	2	3	4	5	6	7
Algebraic Error	-0.58	-1.01	-0.49	.57	-0.15	-2.60	-0.97

TABLE 4

RESPONSE LATENCIES (IN MSEC.) FOR THE SEVEN TREATMENT CONDITIONS: EXPERIMENT III (FIGURE 8).

	Treatment Condition						
	1	2	3	4	5	6	7
Response Latency	1040	1037	1031	1062	1049	986	1071

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

University of Michigan
Department of Psychology
Ann Arbor, Michigan

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

INTERFERENCE IN SHORT-TERM RETENTION OF DISCRETE MOVEMENTS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

Reginald Austin Sorby Adams

6. REPORT DATE

September 1970

7a. TOTAL NO. OF PAGES

99 plus viii

7b. NO. OF REFS

61

8a. CONTRACT OR GRANT NO

AF49(638)-1736 (ARPA)

b. PROJECT NO. 5002

c. 61101D

d. 681313

9a. ORIGINATOR'S REPORT NUMBER(S)

Technical Report No. 24

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

AFOSR-TR- 71-0786

10. DISTRIBUTION STATEMENT

1. This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES

TECH, OTHER

12. SPONSORING MILITARY ACTIVITY

Air Force Office of Scientific Research (NL)
1400 Wilson Boulevard
Arlington, Virginia 22209

13. ABSTRACT

A series of three experiments examined retroactive interference in the retention of discrete movements, and used this technique to examine the encoding of a discrete movement. The apparatus used for this purpose was a manual lever which could swing in a horizontal plane. The lever could be moved by S, or it could be mechanically driven, moving S's arm through some predetermined angle.

The first experiment showed that three additional arm movements interpolated in a 9-sec. retention interval resulted in recall that was significantly poorer than when the retention interval was unfilled.

In the second experiment, the temporal position of interpolated movements within the retention interval was examined. Results showed a significant tendency for recall to be poorer when material was interpolated towards the end of the retention interval. Similarity effects along the dimension of angle size were not found.

In the third experiment, the interpolated material involved different components of a complete movement, as it was argued that those components which were most important for the encoding of a movement would produce the greatest interference. Interpolated material included preparation of the movement, initiation of the movement, and passive movement. Results indicated that forgetting was directly related to the amount of motor output produced by S during the retention interval, which suggests that the most important information used to encode discrete movement is the motor output required to execute that movement.